The Informational Role of Corporate Carbon Performance in the Stock Market

By

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ABSTRACT

This thesis examines the informational role of corporate carbon performance in the stock market using a sample of publicly listed firms regulated under the European Union Emission Trading Scheme (EU_ETS). Based on carbon information compiled from the facility-level records within the transaction log under the operation of the EU_ETS from 2006 to 2015, this thesis calibrates the informational role of corporate carbon performance at the firm-level by exploring: (1) whether corporate carbon performance information affects firms' information environments; and (2) whether corporate carbon performance affects firms' cost of equity.

Employing a synchronicity measure capturing the relative amount of firm specific information flows compared with market- and industry-wide information, the first empirical study in this thesis provides evidence that corporate carbon performance information plays a key informational role in the stock market by impounding more firm-specific information into share prices. In particular, this study finds that: (1) more firm-specific information relative to market- and industry-wide information is incorporated into share prices of firms with less carbon intensity; and (2) leadership in managing carbon performance relative to industry peers increases firm-specific information captured in share prices.

Further, using an ex-ante implied cost of equity measure, the second empirical study in this thesis examines the impact of corporate carbon performance on investors' perception of firm riskiness. This study provides evidence supporting the market assessment of carbon risks manifested in a higher required rate of return on equity. Specifically, this study finds that the magnitude of carbon intensity neither increases nor decreases the cost of equity financing for the full sample. However, a higher cost of equity is observed for high-emitting firms, suggesting that investors condition their assessment of carbon risks on a firm's relative

emission profile. This study also finds that firms with a higher carbon risk profile relative to industry peers have a higher cost of equity, suggesting that firms' capacity to pass-on carbon costs affects the market pricing of carbon risks.

Taken together, the empirical findings of this thesis show that corporate carbon performance serves an important information role in the stock market by producing more firm-specific information that reduces the level of information asymmetry and thereby lowers the cost of equity. This thesis therefore provides confirmatory evidence of the usefulness of carbon disclosures mandated through an enacted ETS.

This thesis contributes to the literature on the market value effects of carbon information in several important ways. First, it provides robust empirical evidence that corporate carbon performance information affects the level of firm-specific information impounded in share prices. Second, this thesis provides unique insights into how corporate carbon performance enhances firm value through the cost of equity.

This thesis also has several important implications for financial market regulators, policy makers, corporate executives and institutional investors. For instance, evidence that firm disclosures of carbon performance provide benefits by enabling industry benchmarking can inform the development of carbon disclosure requirements to improve the transparency of carbon disclosure and the efficiency of capital allocation. Corporate decision makers may take into account the potential benefit of a lower cost of equity in addition to accounting earnings in assessing the viability of investments in green technologies. Further, this thesis has implications for portfolio managers in constructing indices that track firms exhibiting lower carbon profile than industry peers to address the preferences of eco/green investors.

DECLARATION

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree. I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968. I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

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CHAPTER 1

INTRODUCTION

1.1 Motivation and Research Objectives

In a ranking of global risks published by the World Economic Forum (2016), the failure of climate change mitigation and adaptation represents the most impactful risk for the coming decade with other climate-related risks ranking in four of the top ten global risks. In response to the increasing global concern over climate change, governments have implemented policies and regulations to mitigate carbon risks from industrial emissions. In light of the growing importance of business responsibility in managing carbon impacts, there has been an emerging investor response to corporate carbon management through responsible and ethical investing. Reframing climate change as investment risk, many portfolios contain a significant exposure to carbon risks as carbon-intensive firms represent a considerable segment of major global capital markets. Moreover, investors are demanding extensive climate change information from firms, stimulating increased awareness of the importance of incorporating carbon related risks in investment decisions (Ernst & Young, 2012c; UNEP Finance Initiative, 2013).

The objective of this thesis is to investigate the capital market consequences of corporate carbon performance. The value relevance literature suggests a role for firms' non-financial performance in reducing information asymmetry by providing incremental price-relevant information beyond accounting information (e.g., Cahan et al., 2016; Clarkson et al., 2013; De Klerk, 2015; Dhaliwal et al., 2011). Despite growing interest in firms' climate change responses by institutional investors and an increasing recognition of carbon risks on firms' operational sustainability underpinning environmental management theories, there is little empirical evidence on the informational role of corporate carbon performance in capital markets, or market participants' perception of firms' carbon risks. Hence, this thesis examines the information usefulness of corporate carbon performance and its impact on the perception of firm riskiness in a capital market setting.

Global warming and concerns about climate change underlie public awareness of corporate responsibility in managing carbon impacts. In light of the growing recognition of the importance of business response to the climate change challenges, various emissions trading programs have been established to assign a price to carbon emissions. Traditional economic theory suggests that commitments to any form of environmental protection will divert firms' financial resources away from productive investment to absorb a previously externalised cost that is not compensated for through an increase in return (e.g., Friedman, 1970; Palmer et al., 1995; and Walley and Whitehead, 1994). In the context of a carbon pricing mechanism, there is a growing concern that the emerging carbon constraints may restrict business growth, thereby adversely affecting firm performance and value (Carbon Trust and Cairneagle Associates, 2006; Ellis et al., 2010; Ernst & Young, 2012b; Rutherford, 1992).

The carbon price that a firm has to absorb through an emission trading scheme makes the exposure to current and future carbon costs an important risk that firms need to incorporate into their business strategy for long-term operation and sustainable growth in a carbon-constrained future (Busch and Hoffmann, 2007; Clarkson et al., 2015; Kolk et al., 2008; Stubbs and Lockwood, 2007; Subramaniam et al., 2015). Consequently, as regulations to reduce carbon emissions significantly tighten over time, the growing recognition of reframed financial risks associated with the corporate response to climate change in the past decade has been accompanied by increasing demand for more carbon disclosures by stakeholders with accounting regulators involved in establishing reporting requirements (Institute of Chartered Accountants in England and Wales, 2004). There is a general consensus in both academic and professional literature that investors use a firm's emission level to assess its carbon liability in the absence of a standardised accounting treatment (c.f., Clarkson et al., 2015; Griffin et al., 2017; IRRC Institute and Trucost, 2009; and Matsumura et al., 2014).

The associated financial implications of the corporate response to reducing carbon emissions has, understandably, raised serious questions and intensified the debate among corporate executives, environmental groups, institutional investors, accounting regulators and academics: Should firms report carbon performance along with other financial information? What role can investors play with better corporate carbon disclosures? Can firms benefit from a proactive approach towards reducing carbon impacts?

The past decade has seen a rapid growth in voluntary carbon disclosure as a primary means by firms to cope with growing pressure from the investment community for information about firms' carbon-related risks and opportunities. The most significant influence to date is the Carbon Disclosure Project (CDP), representing over 800 institutional investors with $US100 trillion of assets under management in 2015. The CDP signifies a voluntary initiative to standardise corporate carbon reporting procedures with the purpose of providing information relevant to investors to incorporate climate-related businesses risks and opportunities, in addition to information disclosed in the financial accounting system, into valuation and investment decisions.

Nevertheless, despite a high response rate by firms, concerns have been raised about the extent to which the information disclosed through the CDP is useful to investors in their valuation analyses, particularly because of the limitations in reliability and comparability (Kolk et al., 2008). First, the lack of an external verification process puts reliability at risk (O'Dwyer et al., 2005). In addition, analyses of responses in the CDP indicate a high-level of show-casing or potential green-wash, with significant inconsistencies both within and between industries. Second, the lack of a common metric for carbon remains a major challenge (Levin and Espeland, 2002). Furthermore, carbon disclosures may not deliver comparable information over time, because of various additions and deletions of questions, and across firms, as a result of the diversity in responses provided. As with other information, notwithstanding its potential relevance, if carbon disclosure was unreliable or incomparable, it would not be useful for assessing the financial impact of carbon reduction across firms and, consequently, would not meet investors' information needs.

In 2013, the UK Government took the lead in transforming carbon disclosures into mandatory carbon reporting under the *Companies Act 2006* (Strategic and Directors' Reports) Regulations 2013, along with the introduction of the Climate Change Reporting Framework as a method of compliance. Included in the regulations are two key compulsory disclosure requirements: (1) comparative emission levels for both the current and previous period, except for the first reporting period, in the director's report; and (2) conversion into an intensity ratio. These regulations are based on the broad assumption of capital market benefits through mandatory reporting of carbon emissions with benchmarks. The reporting aims to provide investors with comparative carbon information within a firm and across firms, empowering investors to incorporate corporate carbon performance into investment decisions.

In contrast, policy makers in other jurisdictions contend that the compulsory requirements of compiling carbon disclosures in directors' reports would result in the duplication of information provided via other sources (Huber, 2014) (i.e., reporting rules promulgated by environmental regulations) such as an enacted emission trading scheme. Compliance with additional reporting requirements may place a burden of extra costs on firms because of data management challenges, coordination among environmental managers and other senior executives from a variety of departments and potential proprietary costs (Li et al., 1997; Paddison, 2013; Scott, 2012). In addition, some observers have raised concerns that a mandatory approach may also discourage firms from exploring material issues specific to the firm and restrict firms to a checklist method to transparency (Business for Social Responsibility, 2010). Accounting standard setters and security market regulators advocating effective disclosure and alternative legal principles governing corporate disclosure obligations have argued that as directors' reports become thicker over time, the resulting 'information overload' is unlikely to improve investor decision making and may potentially distract investors from focusing on more important information and other business risks (summarised in the following statement from Mary Jo White cited in Ernst & Young, 2014):

"When disclosure gets to be 'too much' or strays from its core purpose, it could lead to what some have called 'information overload' — a phenomenon in which ever-increasing amounts of disclosure make it difficult for an investor to wade through the volume of information she receives to ferret out the information that is most relevant."

— SEC Chair Mary Jo White

While the debate continues globally, the question whether information regarding a firm’s carbon profile contributes to more informative reporting with enhanced transparency on climate change risks remains largely open. Hence, it is important to empirically investigate the extent to which investors view a firm’s carbon profile as useful firm-specific information in the valuation process.

On one hand, extant accounting research reports that capital markets use carbon emissions in assessing latent carbon liabilities even when there are no explicit costs attached to emissions under a carbon pricing program (e.g., Chapple et al., 2013; Griffin et al., 2017; and Matsumura et al., 2014). Despite a wide discrepancy in the price of emissions found in these studies, partially attributable to the high level of estimation involved in the context of voluntary disclosure processes, there is collective empirical evidence of the inclusion of ‘unbooked’ carbon liabilities in the market valuation of firms. These findings lend support to advocates for mechanisms that encourage transparency regarding carbon risks and opportunities to address the increasing information needs from investors.

On the other hand, opponents of mandatory disclosure draw on a broader assumption of capital market benefits. Concerns are raised that the increased cross-sectional comparability of mandated disclosures is at the expense of duplication of information, reduced firm-specific attributes and increased costs for firms (Huber, 2014; Paddison, 2013).

The competing perspectives raised in the context of disclosure issues relating to climate change raise an important and alternative valuation-relevance question: Does information about a firm’s carbon performance complement or compromise firm-specific information content? That is, does information about corporate carbon profile provide economy- and industry-wide comparability at the expense of reduced firm-specific information flow? An important valuation implication is that corporate carbon performance information may affect the market's perception of firms' riskiness through its impact on their information environment.

Accordingly, this study addresses the following two related research questions regarding the information impact of corporate carbon performance within the context of the European Union Emission Trading Scheme (EU_ETS): (1) whether, and if so how, corporate carbon performance influences the extent to which the amount of firm-specific information is impounded into stock prices compared with industry and market-level information, as measured by stock return synchronicity; and (2) whether corporate carbon performance affects investors' perceptions of firm riskiness as revealed by the implied cost of equity.

The EU_ETS represents the world's largest and longest-operating emissions trading system and has been operating more than a decade since its inception in 2005. In the absence of a global reporting requirement of carbon emissions at firm-level, the transaction log under carbon emissions legislation serves as a repository of extensive emissions data. Specifically, emission data for regulated facilities under the EU_ETS are verified and reported annually via the European Union Transaction Log (EUTL), signifying the largest and longest emissions trading database in the world. While previous research primarily focuses on the relevance of carbon emissions in market valuation (e.g., Chapple et al., 2013; Clarkson et al., 2015; Griffin et al., 2017; and Matsumura et al., 2014) and few studies have examined capital market participants' perceptions of firms' carbon performance under the actual implementation of an ETS.

Thus, this thesis responds to the call for research that investigates the consequences of legislation in a novel approach (e.g., Carmona, 2009; and Joshi and Li, 2016). In particular, this thesis seeks to enhance our understanding of the capital market response to corporate carbon performance by examining whether, and if so how, information regarding corporate carbon performance affects firms' information environment and the cost of equity. Further, by studying whether and how corporate carbon performance affects the market valuation process in which a greater amount of firm-specific information is impounded into stock price, this thesis provides important insights into the policy debate as to whether corporate carbon performance disclosure contributes to information efficiency or redundancy.

Central to the policy debate on mandating carbon disclosure in financial reports are concerns that information about corporate carbon risk profile could direct investors' attention away from more important information. Underlying the UK's recent initiative in mandating carbon reporting at the firm level is the view that a standardised, and comparable carbon metric could affect market participants' incentives to collect, process and trade on firm-specific information by understanding the comparative position of firms with respect to challenges arising from climate change (CDSB, 2014). As pointed out in the review of current evidence from reporting of GHG information conducted by the Department for Environment, Food and Rural Affairs (2010), the normative expectations or theoretical benefits, that information about corporate carbon emissions would empower the investor community to incorporate firms' exposure to carbon constraints, are not supported by conclusive evidence of investors' responses to corporate carbon performance. Value relevance studies of environmental performance in general (e.g., Clarkson et al., 2015; Griffin et al., 2017; and Matsumura et al., 2014) are silent on the question whether corporate carbon performance improves or impedes the incorporation of firm-specific information into stock prices. If a comparable carbon measure empowers investors to be able to evaluate and compare corporate carbon performance and incorporate firm-specific carbon information into investment decisions, the information environment of carbon efficient firms is then improved with more firm-specific information captured in stock prices. Accordingly, this thesis investigates whether corporate carbon performance information contributes to more firm-specific information than industry-wide and market-wide information. This thesis also examines whether corporate carbon performance contributes to investors' perceptions of business riskiness reflected in the implied cost of equity. Establishing the information usefulness of corporate carbon performance and the role of carbon risk management in market valuation is fundamentally important for many stakeholders including investors, policy makers, corporate decision makers and NGOs.

In the absence of a standard for carbon accounting, this thesis first analyses whether information about corporate carbon performance summarised into a metric of relative carbon efficiency derived from emission data encapsulated under the EU_ETS provides firm-specific information that is relevant to investors' information needs in valuing a firm. With growing requests from stakeholders for carbon disclosure, empirical evidence from these analyses can enhance our understanding about whether regulatory initiatives are useful in fulfilling information needs by reducing informational imbalance (Berthelot et al., 2003).

Second, a potential interrelated informational role of corporate carbon risk management is to lower the firm's cost of equity as a consequence of improvement in the market's perception of business riskiness. As noted by Clarkson et al. (2013), to serve this role, the carbon information should be perceived as reliable and convey incremental information about the firm's underlying carbon risk. Previous research suggests that effective corporate voluntary disclosure and security regulations can lower firms' cost of equity through a reduction in information asymmetry and agency problems (e.g., Botosan, 1997; Dhaliwal et al., 2011; and Hail and Leuz, 2006). This thesis focuses on firms regulated under the EU_ETS where carbon emissions are mandatorily disclosed through an external non-firm source using a trading log. In this way, the information imbalance introduced by firms' self-selection in voluntary initiatives is mitigated. A reduction in information uncertainty using a standardised, comparable carbon metric, as advocated by policy makers, is one channel through which corporate carbon management may affect the cost of equity. Thus, whether corporate initiatives in managing carbon risk can manifest in a lower cost of equity is a joint test of the effect of a reduction in information asymmetry and the effect on the associated risks perceived by capital market participants.

Third, this thesis focuses on a potential benefit in the form of a lower cost of equity for firms that demonstrate leadership in carbon reduction compared with their industry peers. The cost of equity financing, and expected return on corporate investment, are fundamental constructs in firm valuation from both the perspective of the firm and capital market participants. The cost of equity capital is the required rate of return demanded by equity investors, given the market's perception of a firm's riskiness (El Ghoul et al., 2011). Corporate carbon risk management may reduce the perceived riskiness by reducing the uncertainty of future cash flows by mitigating regulatory, physical and business risks (Jung et al., forthcoming). Thus, environmental management theories suggest that the more carbon efficient firms should benefit from lower equity financing costs (e.g., Sharfman and Fernando, 2008). In other words, the perceived lower risk is reflected in the acceptance of lower risk premiums on equity by investors. Consequently, a lowered cost of equity could be a channel through which capital markets encourage firms' carbon efficient investment (El Ghoul et al., 2011; Heinkel et al., 2001).

Previous studies provide evidence that carbon emissions are penalised by investors in the market valuation of equity (e.g., Clarkson et al., 2015; Griffin et al., 2017; and Matsumura et al., 2014). However, market-value implications reflect both the numerator effect of changes in the expectations for future cash flows and the denominator effect of changes in the perceived risk of these cash flows. A lower cost of equity because of a reduction in the risk perception of future cash flows attached to carbon constraints can be separated both conceptually and empirically from improved financial performance because of enhanced carbon efficiency. While improved efficiency resulting from incorporating climate change opportunities into strategic internal investment is relevant to the capital market, a spill-over effect from institutional and external influences (such as SRI funds) can also have profound value implications (Aktas et al., 2011). Nevertheless, little attention has been devoted to the external influence of carbon risk on firm value. It is important to establish how corporate carbon risk management is ultimately reflected in the cost of equity because it is a key input in firms' long-term investment decisions with ensuing implications for strategic planning and resource allocation. Hence, this thesis seeks to provide important insights into the potential benefit associated with corporate carbon risk management perceived by capital market participants through an examination of the effect on the implied cost of equity.

1.2 Summary of Major Findings

Using panel data of publicly listed firms regulated under the EU_ETS from 2006 to 2015[1], this study investigates two related capital market responses to corporate carbon performance. The first empirical study (Chapter 5) examines whether and how firms' carbon performance affects different types of price-relevant information. In particular, this study sheds light on whether a firm's carbon risk profile influences the amount of firm-specific information relative to industry-wide and market-wide information impounded in stock prices. The second empirical study (Chapter 6) explores the market pricing of carbon risk using the implied cost of equity based on stock prices and ex-ante earnings forecasts.

Chapter 5 investigates whether corporate carbon performance information affects a firm's information environment as measured by its stock return synchronicity. This study provides empirical evidence that a corporate carbon risk profile contributes to share price informativeness. The analysis is based on the stock return synchronicity framework developed by Morck et al. (2000) and refined by Piotroski and Roulstone (2004). The results of the multivariate analyses indicate that a corporate carbon management strategy constitutes an idiosyncratic information intervention and contributes to a greater amount of firm-specific information incorporated in stock prices as revealed by the synchronicity of stock returns. Consistent with the prediction, a firm's relative carbon risk profile within an industry conveys incremental firm-specific information beyond a transfer of industry-wide and market-wide information. More specifically, comparable carbon efficiency at the corporate level relative to industry

[1] The collection and compilation of the carbon information are described in detail in Chapter 4.

peers, which can be used to gauge a firm's strategy for managing carbon impacts, contributes to incremental firm-specific information priced into stocks. The results are robust to different model specifications including firm, year and country fixed effects to account for endogenous relations driven by potential bias from omitted variables. Additionally, the breakdown of price changes into different volatility components indicates that a firm's carbon risk profile is significantly associated with both systematic and idiosyncratic risk, but is not associated with stock price crash risk. These observations consistently show that investors incorporate climate-change related information specific to the firm into valuation processes.

The second empirical study (Chapter 6) examines the market perception of a firm's carbon risk. By imputing a firm's ex-ante cost of equity implied by its stock price and earnings forecasts as a more direct proxy of expected return on equity, this study provides evidence on the market perception of carbon riskiness. In contrast to the prediction, a firm's carbon intensity neither increases nor decreases its cost of equity. Nevertheless, the market pricing of carbon risks appears to be conditional on firm's relative emission propensity, with a positive association observed between emissions from high-emitting firms and their cost of equity, while emissions from low-emitting firms are not priced. The results are robust to an alternative measure of the cost of equity and remain consistent after correcting for any earnings surprises potentially driven by optimism in long-term earnings projections. The findings are also robust to alternative specifications of the model for time and industry considerations.

1.3 Contribution

This thesis seeks to advance the literature by testing the impact of corporate carbon performance on the relative amount of firm-specific information flow impounded in market value and the impact of corporate carbon risks on market value through the cost of equity. In an attempt to establish the information usefulness of carbon management in market valuation and enrich our understanding about whether firms' strategies towards managing carbon impacts are valued by market participants, this thesis extends and contributes to various strands of prior literature in several ways.

First, this thesis contributes to the environmental accounting literature, in particular, concurrent research in carbon accounting by investigating the information usefulness of corporate carbon performance. Prior literature has investigated the link between firms' environmental and financial performance using accounting-based and market-based measures (e.g., Clarkson et al., 2004; Clarkson et al., 2011; Cormier and Magnan, 1997; Sharfman and Fernando, 2008; and Spicer, 1978). The extant research has largely focussed on environmental performance or broader CSR issues with increasing attention given to more specific climate-related issues of high-profile more recently (e.g., Clarkson et al., 2015; Griffin et al., 2017; Jung et al., forthcoming; and Matsumura et al., 2014). Carbon emissions are globally subject to increasing regulatory scrutiny because of shifts in government policies with ensuing business consequences. Consequently, the growing recognition by various stakeholders, including policy makers, corporate decision makers and investors, of carbon constraints on business operations makes carbon emissions a key non-financial performance metric. Most empirical CSR/environmental performance studies rely on broad CSR/environmental metrics that are often provided by a third party rating agency, such as the widely used KLD scores (e.g., Deng et al., 2013; El Ghoul et al., 2011; Hassel et al., 2005; and Khan et al., 2016). In contrast, the transaction log accompanying the operation of the EU_ETS provides a comprehensive and more objective source of data to evaluate carbon performance as a result of the nature of a mandatory and verified reporting system standardised by regulations. However, there is little direct evidence of the association between corporate carbon risk profile and relative price sensitive information flows. The empirical evidence contributes to existing literature by showing that better carbon performance improves the information environment by impounding more firm-specific information into stock prices.

Second, this thesis contributes to the literature by extending the realm of existing research from the impact of carbon emissions on stock prices to the impact on the relative amount of firm-specific, industry-wide and market-wide information incorporated into stock prices. Existing literature establishing valuation relevance of firms' emission profile does not provide insights into the role of firm-specific carbon-related information versus market- and industry-wide information. By investigating the type of price-relevant information conveyed by firms' carbon risk profiles, this thesis provides direct insights into whether information about a firm's carbon footprint encourages or suppresses firm-specific information. Recognising that carbon risk is asymmetric across industries, Clarkson et al. (2015) use the Herfindahl–Hirschman index as a proxy for market power to capture the potential different valuation impact on carbon emissions. While Clarkson et al. (2015) provide preliminary evidence on heterogeneity in the market assessment of carbon emissions from different industries, the relative importance of carbon management from an industry effect or firm effect during the valuation processes is not directly investigated. Specifically, this thesis extends Clarkson et al. (2015), which examines the value-relevance of carbon emissions, by providing direct evidence on whether firms' commitments in mitigating carbon risk provide more price-relevant firm-specific information beyond industry- and market-wide information. Using a multi-industry design, this thesis reports that more firm-specific information is incorporated in share prices of firms that demonstrate leadership in carbon performance relative to their industry peers. Further, it documents the intra-industry transfer of information to firms with a high relative carbon profile.

Third, this thesis contributes to the environmental and financial management literature by conducting an analysis of the market pricing of carbon riskiness. Despite increased awareness of the need for investors to incorporate firms' carbon risk into valuation analyses, there is little direct empirical evidence on the market perception of firms' carbon risk. Previous studies investigating the relevance of corporate carbon management indicate investors incorporate information about carbon emissions into valuations (e.g., Clarkson et al., 2015; Griffin et al., 2017; and Matsumura et al., 2014). The firm value implications reflect efficient carbon utilisation and/or effective carbon risk management. Though an emerging body of carbon management literature provides evidence on improved operating efficiency and financial performance resulting from investment in carbon efficiency (e.g., Sinkin et al., 2008; and Tang and Luo, 2014), little attention has been given to market perception of corporate carbon risk management as an external influence in firms' investment decisions. This thesis explicitly addresses the ex-ante assessment of corporate exposure to carbon riskiness by investors in the capital market. A related study conducted by Chen and Gao (2012) examined the market pricing of carbon risk using the implied cost of equity. They focused on a sample of US public firms operating in the electric utility industry regulated under the emission program administered by the US Environmental Protection Agency. However, this thesis differs from Chen and Gao (2012) in capturing the market response to carbon risk under more stringent regulatory scrutiny and across industries. First, this thesis examines European firms that are participants in the EU_ETS. Europe and the US are significantly different in terms of the institutions and disclosure requirements related to climate change, with Europe having the world's first carbon pricing system and more stringent regulations than the US. Second, Chen and Gao's (2012) sample is limited to facilities operating in the electric utility industry because of data constraints from the Emissions and Generation Resource Integrated Database. However, exposure to carbon constraints is not limited to one industry. The multi-industry design of this thesis allows an investigation into differences in the magnitude of priced carbon risk across firms as well as potential differences attributed to industry effects. The use of emission data from the actual operation of the carbon trading system in the EU provides a wider variety of carbon metrics and industry coverage. In particular, this thesis contributes to the literature by providing empirical evidence that investors demand a higher rate of return on equity from firms exhibiting a high carbon profile relative to their industry peers.

1.4 Implications

In summary, the findings from this thesis provide important insights into whether and how capital market participants respond to carbon data manifested in the EU_ETS in pricing stocks, and whether firms demonstrating better carbon performance have lower perceived risk by investors manifested in a lower cost of equity. The results from this thesis have important policy implications for carbon disclosures in the business context and the efficiency of capital allocation in capital markets in light of the ever pertinent climate reality since emission trading regulations are likely to accelerate, especially given the global agreement signed by 175 countries in Paris on the reduction of climate change at the United Nations Climate Change Conference in 2015.

The findings may assist accounting and market regulators, such as the Carbon Disclosure Standards Board [2], with potential future deliberations on corporate disclosure requirements for carbon-related information to address the growing information needs in this expanding field. Whether a common metric can deliver more decision-useful carbon information for investors is an important question attracting growing attention. The finding of the first study, that emission data substantiating firms' commitments in reducing carbon emissions relative to industry peers represents firm-specific information that is relevant to stock valuation, implies that annual intra-industry ranking of carbon efficiency enhances market participants' understanding of the carbon-related risks and opportunities specific to a firm. Leading carbon mitigation practices within a carbon-intensive industry is a firm-specific valued component in addition to common information extracted from industry-level signals.

This thesis provides useful insights into the two major roles served by a common carbon metric in meeting information needs. First, it conveys information unique to the firm, allowing investors to assess the effect of a firm's proactive efforts in managing carbon impacts and their implications for corporate sustainability and economic resilience. Second, it facilitates the intra-industry transfer of information. This suggests that to be

[2] The Carbon Disclosure Standard Board aims to develop a GHG reporting framework to provide investors with decision-useful carbon information, thereby promoting a resilient capital market.

more useful to investors, a standardised carbon metric should not only capture corporate historical carbon emissions denominated in an efficiency ratio, but also the relative competitiveness in the sector in which the firm operates. Thus mandating disclosure of an efficiency ratio in annual reports, though alleviating the information imbalance among investors, may not be sufficient for complete intra- and inter- industry assessment.

A firm's carbon management strategy is a long-term commitment that is not readily observable or quantifiable. Thus, the empirical evidence reported in this thesis on whether the capital market is able to discern corporate carbon management strategies through emission data over time and reward the firm with less exposure to carbon emissions through a lower risk premium, has important implications for both external and internal users of firms' carbon information. The evidence that firms exhibiting leadership in managing carbon profiles relative to industry peers enjoy a lower cost of equity is potentially relevant to corporate management. Arguably, this insight may reinforce managers' proactive strategies in reducing carbon emissions, thus benefiting the firm through lower equity financing costs, as well as contributing to a more sustainable economy. In addition, the market perception of business riskiness by investors in the form of financing costs, itself serves as important financial management information in firms' investment decisions. Managers of high-emitting firms may be made more aware of the benefits of adapting to a carbon-constrained economy, such as attracting capital investment flows and reducing their firm's cost of equity.

Additionally, the insight into the role of an accumulation of surplus allowances in mitigating the higher cost of equity for firms with higher carbon risk profiles is potentially useful to management in developing strategies for managing risk in a carbon constrained economy. A surplus allowance account may help to project a clean image because of permanent mitigation effects, thus reducing exposure to future carbon risks.

Finally, this thesis provides evidence on the informational role of corporate carbon performance in the stock market, which may be of particular interest to investors. The insignificant association between a firm's absolute carbon performance and the implied cost of equity suggests that the market appears to be indifferent to firms with high or low carbon intensity ratios. This is consistent with the investment perspectives in Credit Suisse (Aulisi and Schuster, 2015) that investment decisions merely based on a carbon intensity ratio may introduce a sector tilt in the adjustment of equity holding towards less carbon-intensive sectors, thus potentially increasing exposure to other risk factors. In other words, excluding carbon-intensive stocks from a portfolio may introduce undesired volatility exposure, tracking error or industry tilt competing with other investment objectives. As indicated by further analyses in Chapter 5, a firm's carbon performance is also correlated with other types of investment risk, both systematic and idiosyncratic risks.

According to the theoretical frameworks introduced by Merton (1987) and Heinkel et al. (2001), idiosyncratic risks attached to a firm's carbon emissions may reduce opportunities for risk diversification because of investor preferences and information uncertainties. Consequently, higher perceived risk may give rise to a higher cost of equity. Another possibility is that accepting a lower equity premium is one channel through which investors voice their endorsement of corporate policies to reduce a firm's carbon footprint. Regardless of the underlying mechanism, the evidence presented in this thesis that a lower cost of equity is attributed to a firm's leadership in managing carbon impacts relative to industry peers, implies that the investor community is a source of external influence on the firm. For example, as argued by Kolk et al., (2008), norm-constrained investors have the potential to institutionalise corporate strategic choices towards low-carbon investment through their investment decisions. These insights have several implications for the investment community, including: for portfolio managers, the importance of monitoring the introduction of other types of risk while lowering exposure to carbon emissions; and, for financial advisors, the need to recognise and address the preference of some investors for green investment in their recommendations.

1.5 Thesis Structure

The remainder of this thesis is organised as follows. Chapter 2 provides an overview of the regulatory background for emission policies and the EU_ETS. The existing literature on the broader issue of environmental risk and an emerging stream of carbon risk in the context of capital market research is reviewed in Chapter 3. The theoretical perspectives developed in the environment management literature inform the predictions in the subsequent empirical chapters. Chapter 4 provides a detailed description of the data collection procedures for a sample of firms regulated under EU_ETS. In addition, Chapter 4 details the construction of the carbon-related metrics examined in the subsequent empirical chapters. Summary statistics relating to carbon emission data are also presented in that chapter. Chapter 5 reports the empirical investigation into the effect of corporate carbon performance on stock return synchronicity, which indicates the relative amount of firm-specific, industry-level and market-level information incorporated into stock prices. Chapter 6 examines investors' perception of firms' carbon risks by investigating the effect of carbon performance on the implied cost of equity. Finally, Chapter 7 concludes by summarising the findings of the empirical analyses and discussing their limitations. That chapter also discusses the contribution and implications of the studies and provides suggestions for further research.

CHAPTER 2

REGULATORY BACKGROUND

2.1 Introduction

This chapter provides an overview of the regulatory context of global climate change policies. Section 2.2 describes the Kyoto Protocol that signified an international commitment to combating global climate change followed by its implications for the establishment of carbon markets. Section 2.3 provides an overview of the European Union Emission Trading Scheme (EU_ETS), thus providing a background to the operation of a carbon market that is the context of the investigations conducted in this thesis. Section 2.4 discusses the accounting issues pertaining to the trading transactions arising from a market mechanism for emissions. Finally, a summary is provided in Section 2.5.

2.2 Kyoto Protocol

Underlying the current carbon regulations around the world in the past decade is the Kyoto Protocol adopted in 1997. The Kyoto Protocol to the United Nations Framework Convention on Climate Change is an international environmental agreement dealing with concern about anthropogenic-induced global climate change. The Kyoto Protocol prescribed legally binding obligations on industrialised countries (Annex I ratifying countries) to collectively reduce emissions of greenhouse gases (GHG) by an average of 5% compared with the 1990 baseline by 2008-2012. This also heightened awareness of the imminence of combating anthropogenic-induced global climate change as well as the accountability of firms to stakeholders for their non-financial performance in addition to financial performance (Kolk et al., 2008).

The targets identified in the Kyoto Protocol consequently necessitated global efforts and national government policies towards reducing GHG emissions. Employing a pricing mechanism to carbon emissions, the carbon market is one key policy instrument to facilitate and fulfil the commitment to GHG emission reduction over time. In contrast to a carbon tax system, an emission trading scheme follows the cap-and-trade principle, where the total amount of GHG emission is predetermined with the expectation that the cap will be progressively reduced. This effectively limits the total emissions that can be emitted (Egenhofer, 2007) while allowing participants with a surplus to sell allowances to participants in deficit, with prices set by market dynamics.

Notwithstanding the lack of clarity about some countries' ratification of the Kyoto Protocol before the first commitment period ended in 2012, there have been noticeable global efforts towards low-carbon economies under the Kyoto framework. Furthermore, the international landscape is evolving towards a reduction in emissions, incentivised by linked trading schemes. The world's first carbon market, the ETS established in 2005, is EU's flagship policy framework towards combating climate change. To provide a background to these studies, the next section discusses the development and implementation of the EU_ETS.

2.3 Emission Trading Schemes

Though there is yet no global carbon market, a dispersed set of cap-and-trade systems has been developed and implemented in various jurisdictions. Taking a leading global role to over-achieve the target under the Kyoto framework, the EU-15 member states jointly aimed to reduce GHG emissions by 8% below 1990 levels by 2012. The EU_ETS was implemented in 2005, being the longest-standing and by far the largest international GHG trading system, with the three-year pilot phase commencing from 2005, followed by more stringent allocations in the second and third phases, from 2008-2012 and 2013-2020, respectively. Shifting towards the third phase in 2013, the EU_ETS then covered over 11,000 installations from emission-intensive industrial activities, including power stations, refineries and offshore operations, iron and steel, cement and lime, paper, food and drink, glass, ceramics, engineering, vehicle manufacture, and airlines across 31 countries, responsible for over 50% of the EU's total GHG emissions (Ernst & Young, 2012b; European Commission, 2013). After five years of robust growth from an initial $7.9 billion when first implemented in 2005 to $119.8 billion in 2010, trading of the EU_ETS allowances in 2010 dominated 84% of the global carbon market value (Linacre et al., 2011).

As detailed in the guidance on allocation plans issued by the European Commission (2004, 2005), the overall cap is implemented and administered by each member state's National Allocation Plan that determines the allocation of the number of free emission allowances and the number of auctioned carbon allowances. The allocation remains the same throughout compliance years within each phase. By the deadline of each compliance year, participants must relinquish emission to the scheme administrator allowances equal to their actual emissions. Within each phase, participants are allowed to borrow the allowances from the next compliance period or bank unused allowances for future compliance. Participants are also allowed to trade their emission allowances. During the first two phases, most allowances were free allocations but the third phase will see greater use of auctions and trading in lieu of free allocations, with the energy sector receiving no free allocations. Progressively lowering the cap on emissions and allowing participants to trade facilitates reductions in emissions through a cost-effective market mechanism. Apart from the primary instrument of allowances, limited certified emission reduction (CER) credits can also be purchased to extinguish emission liabilities. However, the market for CER is less liquid and ambiguous, potentially because of additional complicated regulatory processes associated with the certification process for the final settlement through the United Nations program (European Commission, 2013).

Since the implementation of the EU_ETS, an increasing number of countries and states have initiated an ETS as a strategy to reduce GHG emissions by collaborating with the EU_ETS (Ernst & Young, 2009). The Regional Greenhouse Gas Initiative covering the power sector in 10 participating states in the US was implemented in 2009. In 2013, California introduced a cap-and-trade program covering large emitting facilities. New Zealand has had a national ETS since 2008 and South Korea launched its first nation-wide ETS in 2015. China, as one of the most rapidly growing economies and largest carbon emitters in the world, launched a pilot ETSs in 2012 covering seven areas; the intention is to build towards a nationwide carbon market by 2017. Moreover, the EU_ETS has been contemplating linkages to various regional ETSs around the world with a prospect of forming an OECD-wide carbon market, expanding to developing countries by 2020 (Ernst & Young, 2012a).

Global efforts towards a low-carbon economy have created an impetus for affected companies to incorporate climate change risk management strategies into corporate decisions to sustain business competitiveness. Accordingly, it is important to understand the financial implications of related emission trading disclosures.

2.4 Accounting and Disclosures for Carbon Related Issues

Implicit in an emission trading program is the extension of firms' accountability for non-financial performance through a process involving economic consequences related to emission levels and the associated accounting requirements for related emission trading activities. Although there is a lack of definitive guidance on the accounting requirements for emission allowances, mandatory emission reporting requirements are incorporated in the ETS. These disclosures thus intensify institutional pressures on companies to respond to climate change risks (Kolk et al., 2008).

In December 2004, the International Financial Reporting Interpretations Committee issued IFRIC 3 Emission Rights, which was the first authoritative accounting guidance on accounting for emission allowances. However, the European Financial Reporting Advisory Group criticised IFRIC 3 for the asymmetric treatment of emission rights and emission liabilities, with changes in liabilities recognised immediately through profit or loss whereas changes in assets were recognised in other comprehensive income and accumulated in equity, leading to additional earnings volatility. Consequently, despite the consistency with accounting standards, IFRIC 3 was withdrawn six months after being issued because of the unsatisfactory reporting mismatches among other shortcomings (Ertimur et al., 2017).

In general, EU companies account for emission allowances as intangible assets or financial assets using either a gross approach or a net approach (ACCA, 2010). Under the gross approach, allowances are initially recognised at fair value and subsequently measured at cost, adjusted for significant reductions in value if considered permanent. Emission liabilities are recognised separately as incurred. They are measured at the carrying amount of the allowances held but any shortfalls beyond the allowance held are measured at the market value of allowances.

In contrast, the net liability approach applies an overall recognition of both assets and liabilities. It follows the same rationality as the separate approach in terms of the definition, except it recognises allocated allowances at a nominal amount where the nominal amount is zero for free allocations. Emission liabilities covered by allowances held are recognised at the carrying amount of those allowances and any deficit is measured at market value. When the entity holds sufficient allowances to meet the emission obligations, the resulting surplus is effectively not recognised because the carrying amount of allowances held are zero. Thus, only deficits are captured at market value in the provision for future emission obligations under the net liability approach.

Since the withdrawal of IFRIC 3, there has been no authoritative guidance on accounting for emission allowances, resulting in alternative approaches being applied by individual entities in practice. In light of the development of ETS, the International Accounting Standards Board has added this issue to the International Financial Reporting Standards agenda in 2012 and initiated research projects to inform the discussion (IFRS, 2015; IPSASB, 2014)

In general, environmental reporting varies under different jurisdictions and environmental regulations, and has developed voluntarily. While environmental disclosure remains largely voluntary, there are some mandatory reporting requirements attached to carbon trading schemes regarding objective matters. Under the *Companies Act* 2006, the UK Government has recently mandated carbon reporting for listed companies on the London Stock Exchange in 2013. This new regulation is underpinned by the expectation that mandatory disclosure about firms' risks associated with climate change can empower investors to exert institutional pressure on companies to expedite emission reduction.

2.5 Summary

In light of the increasing awareness of combating global climate change, various emission policies have been established to address industrial emissions. The initiation of the EU_ETS in 2005 is EU's flagship policy instrument to reduce greenhouse gas emissions and represents the largest carbon market in the world. Despite a lack of authoritative accounting guidance on reporting issues, participants' emission levels and trading records are maintained by the EUTL. Information provided under mandatory disclosure requirements may play an important role in accelerating responses to climate change risk in business agendas by requiring affected companies to assess and address environmental impacts.

The next chapter reviews the academic literature examining the usefulness of corporate social and environmental performance information predominantly in capital markets and recent literature that focuses on the valuation role of climate change related information.

CHAPTER 3

LITERATURE REVIEW

AND

THEORETICAL FRAMEWORK

3.1 Related Literature

The objective of this chapter is to provide a broad review of the literature on the capital market consequences of corporate environmental management or sustainability practices followed by a review of the recent studies focussing on the firm value implications of carbon emissions. There has been ample research interest in how capital markets respond to the information of firms' non-financial performance[3]. Nevertheless, despite the high profile of risk exposure to carbon constraints in business, the relatively new concept of carbon management has not been adequately examined in prior research. Notwithstanding the belief that information about a firm's carbon profile is useful in investment decisions and empowers investors to engage with companies shifting towards low carbon initiatives, the extant research on the capital market benefits accrued from corporate carbon performance is limited in scope. Most studies focus on the negative impact of firms' carbon emissions on share prices, indicating the value-relevance of emission information rather than the impact of the information in affecting the distribution of value-relevant information flows. Furthermore, prior research has primarily focused on examining the impact of corporate carbon management on operating efficiency rather than an improved market perception of firm riskiness. However, the reduction in firm riskiness also has implications for firm value. The underlying theories that have emerged in the prior research are then identified to inform the predictions in the empirical chapters of this thesis.

[3] The purpose of this review is not to provide an exhaustive list of all these studies; rather it serves to identify the underlying findings from these lines of investigation and to appreciate the theoretical perspectives adopted and the research methods employed, including data sources and measurement, in order to inform the empirical studies in this thesis.

In Section 3.1.1, this chapter first reviews the literature examining the value relevance of pollution information. Due to the nature of different strategies adopted by firms to manage their environmental impacts under regulations, Section 3.1.2 discusses the different environmental management strategies undertaken by firms and their market value implications. Section 3.1.3 explains the market valuation process followed in Section 3.1.4 by an analysis of the scope and limitations of existing carbon and climate change literature. Then, Section 3.2 reviews the relevant theories for hypothesis development. Finally, Section 3.3 summarises the research gaps identified in the existing literature and how they are addressed in this thesis.

3.1.1 Value relevance of environmental performance (pollution information)

Research examining the relationship between market valuation and environmental performance is divided. Some studies follow a negative approach by focusing on the future (off-balance sheet) environmental liability attached to pollution emitted under legislation whereas other studies follow a positive approach, by focusing on the existence of unrecognised intangible assets associated with better environmental management. This strand of research is underpinned by the off-balance sheet nature of many future environmental costs and benefits, resulting from their failure to meet the accounting recognition criteria of liabilities and assets. The negative approach generally focuses on firms' historical pollution information that is required to be disclosed under an environmental regulations (e.g., Chen and Metcalf, 1980; Figge et al., 2002; and Spicer, 1978).

Using water pollution information, Cormier et al. (1993) investigate the implicit environmental liability in relation to corporate pollution indices. Employing an accounting identity valuation model, they find a negative association between the pollution level and market value. Cormier and Magnan (1997) refine the model and obtain results consistent with Cormier et al. (1993), that shares of firms with higher pollution are more heavily discounted. In addition, greater discounts were observed for firms operating in pollution-intensive industries.

Using a two-step analysis, Barth and McNichols (1994) examine the relationship between the number of superfund sites and firms' market capitalisation. They find a negative association between the number of superfund sites and market value after controlling for the estimated future costs, indicating that the liability accrued by the firms was insufficient.

Similarly, in an investigation of highly polluting electric companies targeted by the US 1990 Clean Air Act Amendments, Hughes (2000) finds a discount in stock price that was not captured in the book value for firms with higher emission levels. Hughes also finds the imposition of more stringent environmental regulations increases the value relevance of emission levels. In contrast, Hughes finds that emissions were not value relevant for firms that were not affected by the Act.

Konar and Cohen (2001) distinguish firms' assets into tangible and intangible assets. They find a negative association between poor environmental performance measured by the Toxic Release Inventory (TRI) and firms' intangible assets.

In general, prior research indicates that capital markets assess firms' environmental liabilities using information about pollution. However, the value relevance of environmental information is affected by the intensity of environmental regulation

(Hughes, 2000). Underlying the analyses is the view that firms' historical pollution levels signal their exposure to future environmental liabilities. While this section has focused on environmental liabilities, some environmental performance is in the form of investment in preventing pollution. The next section examines the role of information about environmental management strategies in signalling future environmental performance.

3.1.2 Value relevance of environmental management

This strand of research is underpinned by the environmental economics and management literature suggesting that proactive environmental management enhances firm value. Companies can benefit by sustaining a competitive advantage from greater production efficiency, a notion of 'green goodwill' and raising competitors' costs by promoting a more stringent environmental standard (Clarkson et al., 2011; Hart, 1995; Porter and van der Linde, 1995).

Dowell et al. (2000) investigate the relationship between over-compliance and market capitalisation by explicitly categorising firms' environmental management standards. Over-compliance was defined as the adoption of a more stringent international environmental standard than the regional or US environmental standard. They find Tobin's Q was higher for firms adopting more stringent environmental standards. Using ISO 14001, issued by the International Organization for Standardization, as an external recognition of leading-edge environmental technologies to determine eco-efficiency, Sinkin et al. (2008) observe high firm value for eco-efficient firms.

Klassen and McLaughlin (1996) propose a theoretical model that a corporate strategy of good environmental management through the efficient use of resources can enhance firm value. They find that companies receiving an environmental award realised a share appreciation. In contrast, a more pronounced discount was incurred by companies that released news of an environmental crisis. Similarly, Hamilton (1995) finds firms that received negative news on their TRI emissions subsequently experienced negative abnormal returns on the first release of the TRI information.

Focusing on the pulp and paper industry, Clarkson et al. (2004) find significant, consistent evidence that investors use environmental performance, measured by TRI, to evaluate the potential benefits (costs) of environmental capital expenditure. While capitalisation of expenditure for long-lived assets is required under accounting standards, they find that capital expenditure is positively associated with the market value for companies undertaking proactive strategies only in reducing TRI emissions.

Using the context of mergers and acquisitions, Aktas et al. (2011) examine the value relevance of firms' social and environmental risk management abilities. The sample comprised 106 firm-year observations from 1997 to 2007 for firms followed by Innovest's Intangible Value Assessment for risk management ratings. Their findings suggest that the market rewards the acquirer for acquiring better social and environmental risk management capabilities.

In general, empirical studies of over-compliance do not support the conventional economic wisdom that it diverts financial resources from profitable investment. Rather, there is a general consensus that it 'pays to be green'. In aggregate, empirical evidence is unambiguous in implying that capital markets interpret firms' environmental management strategies for future environmental performance as prospective information to predict future abnormal earnings.

In examining the informativeness of the broader notion of sustainability information in the US capital market, Khan et al. (2016) find that firms rated high on material sustainability metrics significantly outperform firms with low ratings in their future stock returns and future accounting performance. Specifically, they adopt the Sustainability Accounting Standards Board (SASB)'s sector-level classification of material and immaterial sustainability topics and map it to firm-specific ratings based on KLD scores. The SASB adopts a shareholder perspective in identifying materiality and in developing reporting standards for environmental, social and governance issues.

More recently, using a stock price synchronicity measure, Grewal et al. (2017) analyse how disclosures of material sustainability information affect the distribution of information flows reflected in share prices. Based on US firms included in the Bloomberg ESG index for the period of 2007-2014, they find that the firm-level disclosure of material sustainability information according to SASB standards is associated with lower stock price synchronicity. This suggests that material sustainability disclosure enables the incorporation of more firm-specific information.

From the findings of Khan et al. (2016) and Grewal et al. (2017), it is inferred that information revealed through reporting standards developed by market forces may provide incremental firm-specific information relevant to investors, complementing the development of financial accounting standards. However, there is little empirical evidence on the recent high profile issue of the importance of corporate carbon information and its effect on investors' perceptions under legislation.

The mechanical process of firm valuation suggests two possible sources: increased future financial performance and reduced risk profile. A general approach to valuation fails to disentangle these effects (Clarkson et al., 2013). The next section reviews studies based on both the numerator and denominator effect in the valuation process.

3.1.3 Market valuation process

There is ample research examining the relationship between environmental performance and financial performance. The common question is whether better environmental performance leads to better financial performance, hence affecting market participants' assessment of firm value. Empirical evidence generally indicates that better environmental performance is associated with better firm performance using both accounting and market measures (e.g., Al-Tuwaijri et al., 2004; Christmann, 2000; Clarkson et al., 2011; Dowell et al., 2000; Hart and Ahuja, 1996; Nehrt, 1996; and Russo and Fouts, 1997). In particular, Nehrt (1996) incorporated the lead-lag method to investigate causality. He found that early movers can enjoy a higher profit growth for their investment in pollution-reducing processing equipment than those investing later. In addition, Clarkson et al. (2011) provide comprehensive analyses of firms' incentives for adopting proactive environmental strategies and the financial consequences by explicitly controlling for the impact of Granger causality. Using a panel dataset of toxic release inventory from firms operating in the pulp and paper, chemical, oil and gas, and metals and mining industries reported under the US Environmental Protection Agency to estimate firms' trends in managing environmental impact, they found firms experiencing significant improvement in environmental performance in prior periods enjoy improvement in profitability in subsequent periods. Their results also suggest that improvement in environmental performance is preceded by improvement in financial performance, indicating that pursuing such strategies requires financial resources and superior management capabilities to accrue competitive advantages.

In contrast, the studies following the other line of research investigated the role of risk perception in market value and attributed the increased value to the reduced information asymmetry (e.g., Clarkson et al., 2013; Connors et al., 2013; Dhaliwal et al., 2011; Diamond and Verrecchia, 1991; and Plumlee et al., 2015). Only a few studies attempt to investigate the impact of environmental risk management on the cost of capital.

Sharfman and Fernando (2008) find that firms with better environmental performance had a lower cost of equity, which they attributed to improved risk management. It should be noted that implicit in the measurement is the assumption that risk mitigation is achieved by improved environmental performance. However, they find conflicting results for the cost of debt and suggest that future research should be confined to contexts where there is greater pressure on firms to improve environmental performance. Connors et al. (2013) examine the effects of chemical emissions (TRI) on the cost of equity in three of the highest polluting industries, the electric utility, chemicals, and pulp and paper industries, characterised by a greater imperativeness to reduce emission levels. Their results suggest that the management of chemical emissions lowers the firm risk.

In investigating the incremental information provided by firms' voluntary disclosure of environmental performance[4], Clarkson et al. (2013) find firms' cost of equity for a sample of US firms operating in five polluting industries is unrelated to their voluntary disclosure of environmental information. They also observe that the cost of equity has a significant positive association with environmental performance information based on TRI reported to the EPA, consistent with Sharfman and Fernando (2008) and Connors et al. (2013). Clarkson et al. (2013) thus conclude firms' voluntary environmental disclosures provide no incremental relevant information beyond actual emissions data in TRI to investors for the assessment firms' environmental risks.

Of more direct relevance to this thesis, Chen and Gao (2012) investigate the relationship between carbon emissions and the cost of capital for a sample of US firms. They find that firms' implied cost of equity and implied cost of debt are positively associated with emission rates sourced from the Emissions and Generation Resource Integrated Database (EGRID) issued by the EPA. Because of the data constraint in using EGRID to capture climate risk, their research scope is limited to the US electric utility industry.

These results highlight the important role of information encapsulated under environmental regulations in providing a signal of future environmental performance. Reduced environmental risk by enhanced environmental performance changes investors' perceptions of corporate future risk profile and therefore reduces the expected return demanded by investors.

[4] There is empirical evidence on the relationship between firms' voluntary disclosures and actual environmental performance across different regulatory contexts; see, for example, Clarkson et al. (2008), De Villiers and Van Staden (2011), He and Loftus (2014), Oates and Moradi-Motlagh (2016), and, more specific to the carbon topic, Qian and Schaltegger (2017).

3.1.4 Carbon (GHG) emissions and climate change literature

Research on the value relevance of carbon emissions in capital markets has focused on the negative impact of emissions. Matsumura et al. (2014) examine the relationship between firm value and carbon emissions for the US S&P 500 firms using data reported in the CDP survey, where GHG disclosures are voluntary initiatives in the absence of an ETS. Their results suggest a negative impact on firm value of $US212 per ton of GHG for high carbon emitters after correcting for self-selection bias. Further, they estimate that the mean firm value for non-CDP disclosing firms is approximately $5.71 billion lower than that of the nearest neighbour (caliper) matched CDP disclosing firm. Matsumura et al. interpret the lower firm value as an additional penalty for firms not disclosing their carbon emissions to the CDP.

In contrast, Griffin et al. (2017) re-visit the value relevance of emission disclosures to US investors and find an equity discount of $US79 per ton of GHG emissions. They address the problem of self-selection bias by developing a model that estimates the emission level of non-CDP disclosing firms based on firm-level and industry-level characteristics. They then estimate the effect on firm value, based on CDP reported emissions for disclosing firms and estimated emissions for non-CDP disclosing firms. Contrary to Matsumura et al.'s (2014) finding, Griffin et al. (2017) find an insignificant coefficient on the interaction term between the disclosing group indicator and the emission levels, indicating the market does not distinguish between the CDP-disclosed emissions and emissions estimated from other information channels. Based on the results of their estimation model, Griffin et al. (2017) conclude that the negative impact on firm value for non-CDP disclosing firms reported in Matsumura et al. (2014) may be attributable to self-selection bias, such as the residual effects of firm size, which was not completely removed by the propensity score matching procedure. Accordingly, they contend that the use of statistical procedures to control for the voluntary disclosure bias to a single information channel such as the CDP may not be sufficient since investors may be able to obtain information through other information channels. Given that their estimation model incorporates an industry-level information channel, their results indicate possible intra-industry transfers of emission information, i.e., that information about a firm's emission level may also affect the value of other firms within the same industry.

In contrast to the above two studies, Chapple et al. (2013) conduct their study in an Australian context where the implementation of carbon regulation, in the form of a proposed ETS, was anticipated. They find firm value decreased by amounts ranging from 7% to 10% for carbon intensive firms, based on a dichotomous classification of carbon emission intensity, implying an estimated 'future carbon permit price' of \$AU17-26 per tonne of CO2, based on the emission profile of the sample firms.

In general, and consistent with the broader environmental accounting literature, research on the value relevance of carbon emissions suggests that the market impounds the carbon emission information into share prices, even though it is not captured under accounting requirements. However, there is a wide discrepancy in the magnitude of the estimated adverse impact of carbon emissions on firm value, which is partially attributable to the high level of estimation involved in a voluntary disclosure process (c.f., Griffin et al., 2017 and Matsumura et al., 2014).

Where the studies discussed above examine the value relevance of future (unrecognised) environmental liability captured by level of emissions, Johnston et al. (2008) focus on the value relevance of off-balance sheet assets for the future economic benefits of SO2 emission allowances. They argue that emission allowances offer two sources of value: being inventoriable, and a real option. They find that the market positively valued the allowances. However, they failed to observe the hypothesised real option component attached to the allowances when benchmarking against a matched control sample. In contrast to Hughes (2000), Johnston et al. (2008) find the SO2 emission level was not value relevant.

Recently, Clarkson et al.'s (2015) research of the valuation relevance of CO2 emissions under the EU_ETS found that the negative impact from carbon emissions is attenuated for firms with better carbon performance. Hence, the results suggest that in addition to using allowances as an adaptive strategy, as implied in Johnston et al. (2008), firms can also invest in emission reduction to manage carbon risk exposure.

For a sample of Australian firms, Jung et al. (forthcoming) find that the debt market appears to incorporate firms' responses to the CDP as demonstrating awareness and management of their carbon impact, resulting in lower debt financing cost. Their results indicate that the debt market conditioned their assessment of default and reputational risk of historical carbon performance on forward-looking indicators, i.e., an awareness of carbon risk management.

3.2 Environmental Management Theories

Conventional economic theory suggests that the additional costs imposed by environmental regulations to improve environmental performance restrict firms' investment options (Gray and Shadbegian, 1993; Walley and Whitehead, 1994) and are thus profit-reducing. In addition, Friedman (1970) argues that over-compliance with environmental regulations will divert financial resources from profitable investments to meet societal interests for environmental protection. Therefore, improving environmental performance beyond the minimum environmental standard is achieved at the expense of the fulfilment of firms' fiduciary duty to shareholders. In a static context of fixed constraints, conventional economic theory suggests there is a trade-off between social benefits and private costs. Profitable pollution abatement technology would have been adopted voluntarily, leaving no economic incentives to over-comply in a regime of minimum standards (Friedman, 1970). Thus, over-compliance induces a negative impact on firm value.

In contrast to a prediction of mere compliance with the minimum standard under conventional economic theory, existing empirical studies document a wide variation in corporate environmental performance across jurisdictions and time periods, with a more pronounced negative association between environmental performance and firm value observed in pollution-intensive industries where stringent environmental regulations have existed for decades (e.g., Clarkson et al., 2004; Clarkson et al., 2011; Hughes, 2000; Johnston et al., 2008; and King and Lenox, 2001). More importantly, in the context of high-polluting industries, recent evidence suggests firms that are more proactive in improving their environmental performance beyond industry standards are assessed with lower risk, resulting in higher firm value (e.g., Clarkson et al., 2011). Traditional economic theory appears to be inadequate to explain the positive relationship between voluntary over-compliance and firm value (Clarkson et al., 2004).

The environmental management theories suggest a number of incentives for firms to adopt proactive environmental management. Over-compliance is viewed as a source of value-enhancing competitiveness through strategic adaptation to the external environment (Harrison and Caron, 1996; Hillman and Keim, 2001; Porter and van der Linde, 1995). Empirical research on the value relevance of firms' environmental management has primarily emerged from the theoretical framework of a resource-based view of the firm (e.g., Christmann, 2000; Dowell et al., 2000; Hart and Ahuja, 1996; and Russo and Fouts, 1997). The resource-based view suggests that a firm's strategic over-compliance with environmental regulations is a valuable resource and an inimitable capability conferring competitive advantages on the firm over industry rivals (Hart and Ahuja, 1996; Hart and Sharma, 2004; Porter and van der Linde, 1995; Russo and Fouts, 1997).

Socio-political theories explain the benefits of over-compliance as enhanced alignment with stakeholders' interests and societal values. Legitimacy theory posits that failure to meet societal expectations may have a negative impact on an organisation's reputation and disrupt operations culminating in a potential loss of licence to operate. The theory also suggests there is an opportunity to leverage gains in reputation and legitimacy through the alignment of stakeholder interests by conducting environmentally responsible activities (Alrazi et al., 2015; Fombrun and Shanley, 1999; Pava and Krausz, 1996). In explaining firms' voluntary over-compliance with environmental regulations, Arora and Gangopadhyay (1995) modelled a firm pursuing proactive pollution mitigation, which was able to enjoy a price premium as 'green goodwill' derived from superior environmental performance.

Similarly, instrumental stakeholder management theory, which is derived from the economic objective of lowering firms' costs, postulates that firms need to manage and assess their corporate risk profile by incorporating stakeholder concerns in their decision-making processes. Management can thus reduce corporate risk and costs by mitigating threats to organizational legitimacy (Bowie and Dunfee, 2002; Godfrey, 2005; Jones, 1995). Therefore, proactive environmental strategies aimed at addressing environmental concerns may reduce corporate risk by avoiding negative publicity and are thus expected to ultimately lower costs for the firm (Connors et al., 2013; Dhaliwal et al., 2011a; Sharfman and Fernando, 2008).

In summary, a common thread of managerial theories is that superior environmental performance is a valued component specific to firms with supporting resources. Firms adopting proactive environmental strategies can enjoy benefits associated with over-compliance in forms of enhanced operational efficiency (Porter, 1997; Porter and van der Linde, 1995), pre-emptive benefit from industry spill-over effects in environmental standards (Hart, 1995; Lieberman and Montgomery, 1988), risk reduction through increased social legitimacy (Bansal and Clelland, 2004; Sharfman and Fernando, 2008) and ‘green goodwill’ for enhanced reputation (Bansal and Roth, 2000; Dhaliwal et al., 2011).

While some research on the valuation implications of carbon risk management is emerging, there is much scope for further examination under an active carbon market, as discussed in the next section.

3.3 Summary

This Chapter has reviewed studies examining the capital market responses to the broader notion of firms’ environmental performance. The environmental economic literature suggests that market participants incorporate information on carbon emissions into a firm's valuation. Previous research investigating the value relevance of carbon emissions under the EU_ETS document differences in the magnitude of the value impacts of emissions from different industries. This suggests that emission data have both a firm-level and industry- or market-wide information content. However, prior research has not investigated the relative distribution of price-relevant information flows affected by carbon information. In addition, previous studies largely focused on the relevance of firms' emission information to investors while not giving explicit consideration to the presence of intra-industry information transfer. Further, to date, there has been no attempt in the literature to empirically consider the effect of carbon performance on firms' cost of equity in a multi-industry setting under a legislated carbon pricing program. Therefore, this thesis aims to address those research gaps by holistically investigating the capital market effects of corporate carbon performance. First, this thesis examines whether and to what extent carbon performance information influences the amount of firm-specific information impounded in share prices relative to industry- and market-wide information and, second, it investigates whether carbon performance affects the market's perception of firm riskiness as measured by the implied cost of equity.

As a result, evidence from this thesis contributes to the existing literature by providing insights into an important informational role of corporate carbon performance in the stock market through the incorporation of firm-specific information in share prices. Moreover, it provides insights into whether firms' effort in managing carbon impacts is manifested in a lower cost of equity financing, thus establishing one channel through which corporate carbon performance affects firm value. The next chapter provides a description of procedures involved in collecting the emission information data from the

Transaction Log under the EU_ETS and compiling the data from branch-level to the firm-level for use in the empirical investigations.

CHAPTER 4

EMISSION DATA COLLECTION

4.1 Data Collection

The objective of this chapter is to describe the data collection procedures employed in common for the empirical chapters. Section 4.2 details the procedures employed in the construction of the carbon dataset. Section 4.3 elaborates on the construction of the carbon variables. Section 4.4 presents the summary statistics relating to the carbon dataset. Finally, Section 4.5 concludes with a summary of the chapter.

4.2 Sample Selection

The initial sample for this study consists of all publicly listed firms regulated under the European Union Emissions Trading Scheme (EU_ETS) over the period 2006 to 2015. The EUTL provides carbon emissions data and allowance allocations for participating member countries. Following the annual compliance cycle of the EU_ETS, the reported emission measures from each participating installation are verified by an accredited verifier and subsequently published in April the following year. The data compilation procedures employed in this thesis are similar to those adopted by Clarkson et al. (2015).

Firstly, annual verified carbon emissions and allowances extracted from EUTL at the installation level must be aggregated to the corporate level. The data compilation process began by extracting installation information from emission trading accounts followed by the identification of the ultimate holding company of each installation and whether it is listed. The initial number of registered installations participating in the EU_ETS exceeded 16,000 in 31 countries. The emission holding account details obtained for each installation include branch name, address, phone number(s) and registration identifier. Identification of whether each participating installation is a publicly listed entity or is ultimately owned by a listed entity involved a two-step matching process: initially using programming, which was followed up with manual matching based on branch and firm information. Firm listing information was obtained from the Mint Global and ORSIRIS databases, which contain comprehensive information on the controlling entity of companies worldwide and their public status including the name, address, listing status and the ultimate parent of installations. Secondly, for installations ultimately controlled by a listed entity, carbon emissions and allowance data were extracted from the transaction log. The installation-level emissions data were then summed by listed entity and year to arrive at an aggregated emission and allowance measure at the corporate level. A preliminary sample was obtained, comprising 3,872 firm-year observations from 592 listed firms matched to their respective controlling installations in 24 counties during 2006 to 2015. The year 2006 is the first year for which both the carbon data and financial data can be obtained. This sampling period is selected to capture the full implementation of EU_ETS in the decade since its initiation in 2005.

The final sample for empirical tests in the thesis comprises the intersection of the carbon data collected from the EUTL, monthly stock return data obtained from DataStream and the annual financial data obtained from Thomson Reuters, subject to the availability of other variables described in respective empirical chapters. The carbon data collection procedures for all the member countries in Europe are documented in Table 4.1.

Table 4.1. Procedures for carbon emissions data collection

	Procedure	Data Source	Sample Filtering
1	Obtain the holding account details, including the name, location and identifier for each participating installation for the sample period from a structured XML file stored at the emission data repository	European Union Transaction Log	16,370 unique installations from 31 member countries
2	Identify the matching publicly listed entity or ultimate parent entity for each participating installation using a programmed algorithm followed by manual verification	Mint Global, OSIRIS Database & Internet Searches	4,181 unique installations from 27 member countries identified with a listed controlling entity
3	Extract all emission information captured under the emission transactions for all identified installations	European Union Transaction Log	592 unique firms listed in 24 member countries
4	Aggregate all emission variables from the installation-level to firm-level	European Union Transaction Log	3,872 firm-year carbon observations

4.3 Construction of the Variables

This section describes the key carbon variables used in the empirical chapters.

4.3.1 Carbon intensity (CO2)

This study measures firms' carbon performance by computing a carbon intensity ratio. Using total carbon emissions at the firm-level, carbon intensity (CO2) is calculated as total verified emissions scaled by sales, which is widely adopted in environmental performance research to control for production scale (e.g., Clarkson et al., 2013;

Hughes, 2000; Johnston et al., 2008; and Konar and Cohen, 2001). Measuring carbon performance as carbon emissions deflated by the scale of operations is also consistent with both managerial theory and regulatory objective aiming at improving the efficiency of resource utilization (e.g., Porter and van der Linde, 1995).

4.3.2 Carbon risk profile (CO2PRO)

This study also adopts a relative measure of carbon performance (CO2PRO), similar to prior studies (e.g., Clarkson et al., 2004; Clarkson et al., 2013; and Clarkson et al., 2015), to construct a carbon metric that captures both current and future aspects of a firm's carbon risk profile. Previous studies suggest that emission intensity across industries and over time lacks comparability because of endogenous variations in production processes and exogenous economic and technological changes (Clarkson et al., 2004; Hughes, 2000; Johnston et al., 2008). This study sorts firms' relative carbon performance based on the annual industry-adjusted carbon intensity into deciles with a high rank of CO2PRO indicating high carbon profile relative to industry peers. This panel adjustment can effectively control for cross-sectional and time series variations (Clarkson et al., 2004; Clarkson et al., 2015).

4.3.2 Emission allowance surplus (CO2SURPLUS)

This study further analyses the differentiation between firms' carbon management strategies. Following Johnston et al. (2008), conditional analysis was employed to identify firms' strategies from trading information. Based on the verified emissions and submitted carbon allowances, an allowance surplus (CO2SURPLUS) is identified and coded one if there are unused allowances accumulated in the trading account, and zero otherwise. The use of this metric is consistent with the theoretical argument of combined incentives of pre-emptive commitments discussed in the environmental economic literature (e.g., Clarkson et al., 2011; and Nehrt, 1996). This direct measurement of proactive mitigation of emissions also captures firms' riskiness in a carbon-constrained future.

4.4 Summary Statistics

Table 4.2 presents frequency distributions for the sample of 3,872 firm-year carbon observations by country and year. The number of observations was relatively stable across the 10-year sample period with a modest increase from 306 in 2006 to 425 in 2015. The highest number of observations (510) occurs in 2013, which coincides with the commencement of the third phase of the EU_ETS, which brought a significant number of facilities within its scope. However, there was considerable disparity in the number of participating firms represented in the sample from each of the 24 countries in each year. UK firms consistently represented the largest component of the sample, commencing with 66 in 2006 and peaking at 150 in 2013. German firms were the second largest component of the sample, with an average of more than 60 German firms per year. In contrast, fewer than five observations came from each of Bulgaria, Finland, Latvia, Lithuania and Slovakia in each year. Croatia was not represented in the sample until 2014, when one Croatian firm was included in each of the last two years of the sample period.

Table 4.2. Frequency distribution by country and year for the 3,872 firm-year observations for European companies regulated under the EU_ETS over the period 2006-2015

Country	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Austria	5	5	4	6	6	5	5	5	7	6	54
Belgium	14	15	13	13	13	14	14	22	18	19	155
Bulgaria	0	0	3	4	4	4	4	3	3	3	28
Croatia	0	0	0	0	0	0	0	0	1	1	2
Czech Republic	3	2	3	3	4	5	4	5	6	4	39
Denmark	5	5	5	5	5	7	7	7	7	6	59
Finland	2	3	3	2	3	3	3	4	3	3	29
France	35	37	37	36	38	35	36	54	42	39	389
Germany	49	51	54	57	55	58	57	79	77	76	613
Greece	5	7	6	5	5	5	5	5	6	6	55
Hungary	5	5	6	5	6	6	6	6	6	6	57
Ireland	7	8	11	9	8	8	8	15	11	9	94
Italy	23	29	33	27	29	29	33	34	36	33	306
Latvia	1	1	1	1	1	1	1	1	1	0	9
Lithuania	1	2	2	1	1	1	2	1	1	1	13
The Netherlands	17	15	19	19	25	19	25	25	31	30	225
Poland	20	19	19	18	17	18	18	21	19	18	187
Portugal	2	4	5	6	4	4	4	4	6	4	43
Romania	2	2	6	6	5	7	7	6	6	6	53
Slovakia	2	3	3	4	3	3	3	0	2	2	25
Slovenia	2	5	5	5	6	6	6	6	4	3	48
Spain	29	37	36	42	40	44	41	43	40	39	391
Sweden	11	11	14	11	11	11	13	14	15	15	126
United Kingdom	66	69	73	82	82	80	79	150	95	96	872
Total	**306**	**335**	**361**	**367**	**371**	**373**	**381**	**510**	**443**	**425**	**3872**

Figure 1 Geographic localities for the 510 firm observations in 2013

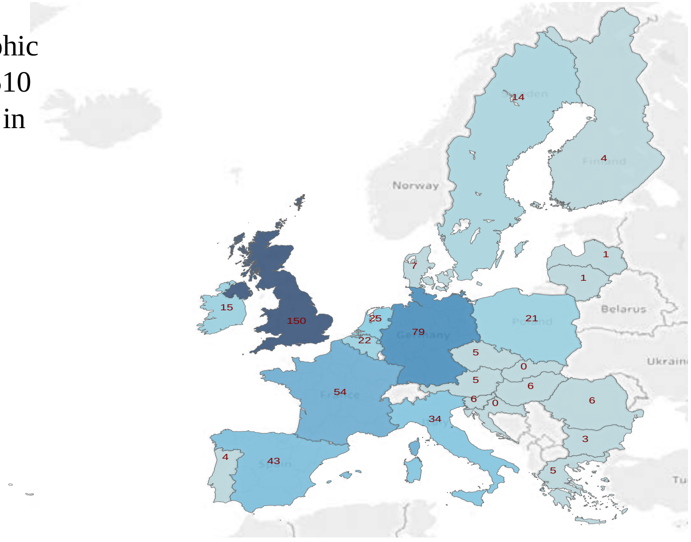

Figure 1 illustrates the localities according to the main location of the 510 firm observations in year 2013. The most observations were primarily located in the UK and surrounding countries in Central Europe. In an untabulated summary, about one third of the firms have more than one installation other than the main listing country, suggesting further analysis considering geographic diversification may generate potential insights.

In terms of industry sector composition, Table 4.3 provides a frequency distribution of the 3,872 firm-year observations accompanied by the summary statistics of the emission profile by industry sector. The industry sectors with the greater representation are highlighted by data bars: the basic materials sector (Sector 1000) with 973 firm-year observations amounting to 25.1% of the total sample, followed by the industrials sector (Sector 2000) with 934 firm-year observations, and the consumer goods sector(Sector 3000) with 821 firm-year observations, together represent 45.3% of the sample observations.

Table 4.3. Frequency distribution and summary statistics of carbon emissions by industry and year for the 3,872 firm-year observations for European companies regulated under the EU_ETS over the period 2006-2015

Industry (Code)	Verified Emissions (Mean)	Carbon Intensity (Mean)	Firm-year Observations	Sector (Code)	Firm-year Observations
Oil & Gas (1)	4.0964	0.1276	302	Oil & Gas Producers (530)	258
				Oil Equipment & Services (570)	24
				Alternative Energy (580)	20
Basic Materials (1000)	1.1574	0.1246	973	Chemicals (1350)	493
				Forestry & Paper (1730)	227
				Industrial Metals & Mining (1750)	202
				Mining (1770)	51
Industrials (2000)	0.7287	0.0959	934	Construction & Materials (2350)	305
				Aerospace & Defense (2710)	77
				General Industrials (2720)	225
				Electronic & Electrical Equipment (2730)	49
				Industrial Engineering (2750)	147
				Industrial Transportation (2770)	49
				Support Services (2790)	82
Consumer Goods (3000)	0.0872	0.0294	821	Automobiles & Parts (3350)	182
				Beverages (3530)	121
				Food Producers (3570)	301
				Household Goods & Home Construction (3720)	96
				Personal Goods (3760)	78
				Tobacco (3780)	43
Health Care (4000)	0.0559	0.0111	222	Health Care Equipment & Services (4530)	68
				Pharmaceuticals & Biotechnology (4570)	154
Consumer Services (5000)	0.4349	0.088	152	Food & Drug Retailers (5330)	1
				General Retailers (5370)	10
				Media (5550)	38
				Travel & Leisure (5750)	103
Telecommunications (6000)	0.0018	0.0001	6	Fixed Line Telecommunications (6530)	5
				Mobile Telecommunications (6570)	1
Utilities (7000)	11.6301	0.3313	203	Electricity (7530)	80
				Gas, Water & Multiutilities (7570)	123
Financials (8000)	0.4066	0.0363	174	Banks (8350)	75
				Nonlife Insurance (8530)	23
				Life Insurance (8570)	1
				Real Estate Investment & Services (8630)	12
				Real Estate Investment Trusts (8670)	1
				Financial Services Sector (8770)	61
				Equity Investment Instruments (8980)	1
Technology (9000)	0.0208	0.0033	85	Software & Computer Services (9530)	17
				Technology Hardware & Equipment (9570)	68
Total	**1.4534**	**0.0938**	**3872**		
Wald Chi-Square Test of Mean Equality	**796.97**	***			
(p-value)	**(<0.001)**				

Notes: Verified emissions is the aggregated annual emissions derived from emission data verified and reported in European Union Transaction Log. Carbon intensity (CO2) is measured as the verified emissions of a firm scaled by sales revenue ($000). The Wald Chi-Square test is for difference in means across industry sectors, allowing for heterogeneous covariance matrices. *** indicates that the mean values for the verified emissions in each industry sectors based on the 3,872 firm-year observations are significantly different at less than the 1% level.

Additionally, the oil & gas sector (Sector 1) has 302 firm-year observations and the heath care and utilities sectors (Sectors 4000 and 7000) have 222 and 203 firm-year observations, respectively. In contrast, the telecommunication and technology sectors (Sectors 6000 and 9000) are represented by only 6 and 85 firm-year observations, respectively. Finally, the consumer services and financials sectors (Sectors 5000 and 8000) were represented by 152 and 174 firm-year observations, respectively. Thus, the sample comprises firm-year observations from important sectors, including both carbon-intensive sectors, such as oil & gas, basic materials, and utilities, which are significantly affected by the EU_ETS, and other sectors, such as financials and technology, that are much less likely to be affected.

The distribution is largely consistent with the industry sector distribution observed in comparable studies investigating firms' carbon impacts (e.g., Clarkson et al., 2015; and Jung et al., forthcoming). Prior literature suggests that firms operating in carbon-intensive sectors are significantly and inherently exposed to higher carbon risk and are therefore subject to higher level of risk assessment relating to carbon issues by investors (Cogan et al., 2008; UNEP Finance Initiative, 2006).

The verified emissions for the sample of 3,872 firm-year observations of European firms from 2006 to 2015 are presented in millions of tonnes in Table 4.3. As revealed by the colour grading, the mean verified emissions and mean carbon intensity display considerable cross-industry variation. Albeit a relatively smaller sample observations, the utilities sector, has the highest emissions on average with a mean verified emission of 11.6301 million tonnes, followed by the oil & gas sector with a mean verified emission of 4.0963 million tonnes. The mean values for their carbon intensity measure (CO2) are 0.3313 and 0.1276, respectively. Hence, on average, firms operating in these sectors emit 0.3313 and 0.1276 tonnes of Scope 1 GHG emissions per $1000 of sales. The next highest carbon-intensive sectors are basic materials, industrials and consumer services; the low carbon-intensive sectors are health care, consumer goods, telecommunications, financials and technology. The Wald Chi-Square test of mean equality is a test of the null hypothesis of no significant difference in the emission profile across different industries, allowing for heterogeneous covariance matrices across industries. As shown in Table 4.3, the test produced a p-value smaller than 0.001. Applying a significance level of less than 1%, the null hypothesis is rejected, indicating that firms operating in different industries exhibit significantly different emission patterns. This result is consistent with prior studies, which provides evidence of differing carbon riskiness inherently associated with industries.

4.5 Summary

In summary, using branch-level emission data aggregated at the firm-level for European firms regulated under the EU_ETS, the sample comprises 3,872 firm-year observations from 2006 to 2015. In addition, the sample distribution statistics suggest that both carbon-intensive and non-carbon intensive sectors are included in the sample with significant variations in emission propensity across industries.

Thus, the descriptive analysis provides the basis for employing industry-year ranking of the carbon profile metric as well as controlling for the industry-wide information in order to address the potential endogenous variation in carbon riskiness arising from industry-level factors.

The next chapter conducts an empirical investigation into the valuation role of carbon performance information in the capital market in conjunction with other firm-level characteristics as well as industry-wide and market-wide attributes.

CHAPTER 5

THE EFFECT OF CARBON PERFORMANCE ON FIRM-SPECIFIC INFORMATION

5.1 Introduction

The purpose of this study is to examine the impact of carbon performance information on the firms' information environment in the context of the EU_ETS. Specifically, this study investigates the valuation role of corporate carbon performance in impounding firm-specific information in stock prices as measured by stock return synchronicity.

Recently, corporate carbon management has emerged as a dominant business theme. The ever increasing government regulations and policies targeting corporate carbon emissions have pressured firms to integrate considerations of carbon constraints in their strategic risk management to ensure sustainable operation (Bui and De Villiers, 2017; Hoffmann and Busch, 2008; Jung et al., forthcoming; Subramaniam et al., 2015; Tang and Luo, 2014). Consequently, the financial implications of corporate carbon risks have resulted in institutional investors' activism in demanding more disclosure about their investment exposure to carbon risks (CDP, 2007; Kolk et al., 2008). Growing societal ramifications over climate change have also raised corporate responsibility in pursuit of green production and sustainable natural resource management beyond the mere objective of profit maximization in traditional economic theory (Busch and Hoffmann, 2007; Freeman, 1984; Porter and Kramer, 2006). A recent survey by Morgan Stanley Institute for Sustainable Investing and Bloomberg (2016) reveals that mainstream investment is adopting sustainable investing practices, with 65% of the 402 asset managers interviewed indicating their current investment in sustainable funds at the demand of clients, implying investors are starting to reward climate leaders.

A large and growing body of interdisciplinary research investigates the economic implications of corporate environmental performance with more attention attached to the recent high profile of carbon risk in response to the unprecedented rising interest in corporate carbon management strategies. Theoretical developments in the environmental management literature provided several motivations for firms' initiatives in reducing their environmental impact, including enhanced cost efficiency, improved brand reputation, better product innovation and increased firm-specific competitiveness, thereby leading to improved operating performance (e.g., Hart, 1995; Nehrt, 1996; Porter and van der Linde, 1995; and Russo and Fouts, 1997). Additionally, the environmental economic literature has long recognised the share price implications of firms' environmental performance, implying that capital market investors incorporate environmental performance as relevant information in their assessment of corporate financial performance and risks (e.g., Barth and McNichols, 1994; Chapple et al., 2013; Clarkson and Richardson, 2004; Hughes, 2000; Johnston et al., 2008; and Klassen and McLaughlin, 1996).

Previous literature also illustrates that environmental information can potentially affect the information environment of a firm by showing that a reduction in environmental impact leads to better prediction of future financial performance (e.g., Clarkson et al., 2013; and Hart and Ahuja, 1996) and a lower cost of corporate borrowing and external financing (e.g., Goss and Roberts, 2011; Jung et al., forthcoming; and Sharfman and Fernando, 2008). More recently, several studies have also demonstrated the impact of firms' emission levels on firm value (e.g., Clarkson et al., 2015; Griffin et al., 2017; and Matsumura et al., 2014).

Although existing studies provide evidence of the valuation relevance of emission information, they do not explicitly consider the effect of emission information on the relative distribution of information flows capitalised into share prices, namely the amount of firm-specific value-relevant information compared with industry- and market-wide information. Thus, a potential important valuation role for corporate carbon performance in improving the transparency of firms' information environment by impounding more firm-specific information into stock prices is under-explored. Hence, this study seeks to extend the extant literature by investigating the impact of carbon performance information on the relative amount of firm-specific information flows, in an attempt to establish one potential benefit to firms adopting a better carbon risk management strategy, an improvement in information efficiency in the stock market.

As suggested by enlightened stakeholder theory, firms can gain competitive advantages by considering stakeholders' interests and thus ultimately increase shareholder wealth (Clarkson, 1995; Jensen, 2002; Wood and Jones, 1995). Specifically, early research in marketing and management has shown that environmentally friendly firms can increase consumer identification and association with their products, thereby enjoying enhanced brand equity by securing long-term contracts with customers (Brown and Dacin, 1997; Carter, 2000; Keller, 1993; Walton et al., 1998). A recent study by Chan and Walter (2014) of investment performance of initial public offerings and seasoned equity offerings found investors of environmentally friendly firms enjoy better subsequent long-term performance, suggesting a persistent "green" premium exists for firms pursuing higher environmental standards.

The early resource-based theory suggests a firm's ability to manage all its internal resources is a valuable and inimitable source of competitiveness specific to the firm (e.g., Barney, 1991). In developing the natural resource-based perspective of a firm, Hart (1995) explicitly incorporated firms' constraints imposed by the biophysical environment. This theory suggests that firms' management capability in natural resources represents 'rare, inimitable, and non-substitutable' firm-specific resources that can eventually provide a source of competitive advantage over industry peers (Russo and Fouts, 1997). Along these lines, previous studies in strategy and operations management suggest implementing higher environmental standards can increase firms' flexibility in managing economic downturn because of their high brand equity (Krasnikov et al., 2009; Walton et al., 1998), minimise supply chain disruption (Carter, 2000) and reduce variability in future cash flows should prices increase (Gruca and Rego, 2005; Sharfman and Fernando, 2008), all of which constitute firm-level resources. This study proposes a testable hypothesis based on the resource-based view of the firm, that better carbon performance represents firm-specific attributes underlying inimitable competitiveness. Hence, a lower emission profile should increase the amount of firm-specific information incorporated into share prices leading to a less synchronous stock return with industry- and market-wide information.

The stock return synchronicity framework has been employed in numerous studies as an empirical construct to evaluate the amount of firm-specific component relative to market and industry components of stock returns (Brockman and Yan, 2009; Gul et al., 2011; Li et al., 2015; Piotroski and Roulstone, 2004). Specifically, using a sample of firms regulated under the EU_ETS from 2006 to 2015, this chapter first investigates whether firms' carbon performance increases the amount of firm-specific information in the stock prices manifested in lower stock return synchronicity. By examining the effect of carbon performance information on firms' information environment, this research responds to the call in the editorial of a recent special issue of the Journal of Management Accounting for research examining corporate sustainability practices in a novel approach (Joshi and Li, 2016). Investigating whether carbon performance information affects the informativeness of stock prices has several implications for management and investors. A growing body of research recognises the importance of the impact of firms' information environment on corporate production and capital allocation efficiency (Chang and Yu, 2010; Durnev et al., 2004). The current study also has implications for investors incorporating emission information into investment decisions. If more firm-specific information is available for firms with better carbon management, investors could rationally engage in stock picking (Li et al., 2015).

The argument based on the resource-based view of the firm highlights the role of an effective carbon management strategy in generating firm-specific resources. The imperative to address public concerns for carbon constraints imposed on business operations is the source of capturing competiveness unique to the firm over sector peers (IRRC Institute and Trucost, 2009). As noted in Collis and Montgomery (1995), the value-relevance of such resources cannot be assessed in isolation from market forces since a resource that is valuable in one industry at a particular time may not be applicable to a different industry or temporal context. Given the unprecedented interest in the financial implications of corporate carbon impacts, using an intra-industry annual rank of carbon intensity to infer relative performance (Clarkson et al., 2015), this research conducts a timely study from both a methodological and conceptual standpoint. Further evidence on the information usefulness of a relative carbon performance metric under an enacted carbon regime provides helpful insights into the comparability of a carbon performance metric. These results of this study are also useful to stakeholders, financial market regulators and policy makers such as the Carbon Disclosure Project[5] and the UK Climate Disclosure Standards Board in their deliberations on the mandatory reporting framework to empower investors through more transparent carbon disclosure potentially integrated into mainstream financial reporting. Comparability of carbon performance information is an important attribute of information usefulness that may assist investors in their evaluation of the carbon intensity from corporate operations and exposure to regulatory and competitive risks (Hassel et al., 2005; Kolk et al., 2008).

This study also provides further investigation into the effect of firms' allowance account balances on the amount of firm-specific information incremental to their carbon performance. Insights into this question are of interest to the accounting profession in the debate over accounting methods for emission rights. Furthermore, this study investigates the effect of carbon performance on stock return variations by disaggregating the components of return variation into market-wide variation and firm-specific variation in an attempt to establish the variation component through which the carbon performance influences firms' information environment. As Li et al. (2014) note, the mixed findings of studies using synchronicity and idiosyncratic volatility measuring the same economic construct is attributable to the correlation between the independent variable of interest and the covariance of firms' returns with market returns. Finally, this study provides additional analyses to examine the relationship between firms' carbon performance and the stock price crash risk where prior literature generates equivocal findings (Kim et al., 2014).

[5] The Carbon Disclosure Project, signifying global institutional investors' demand for more corporate carbon disclosure, aims to standardise reporting procedures to empower investors by providing them with comparable carbon information (CDP, 2007)

Overall, this study provides evidence that corporate carbon performance information plays a key informational role in the stock market by impounding more firm-specific information into share prices. In particular, this study finds that more firm-specific information relative to market- and industry-wide information is incorporated into stock prices of firms with less carbon intensity. In addition, this study shows that leadership in managing carbon performance relative to industry peers increases firm-specific information captured in share prices. Thus, this study provides insights into a potential benefit to firms by demonstrating that the relative amount of firm-specific information impounded in share prices increases with effort in managing carbon risk.

The remainder of this chapter progresses as follows. The next section explains variable constructions and empirical design followed by a section describing the sample and data. The univariate results are presented first followed by regression results from multivariate analyses. This chapter also provides additional results in the section of further analyses. The robustness section provides a series of sensitivity analyses and the final section provides a summary of this study.

5.2 Variables Construction and Empirical Design

This section describes the construction of the dependent variable, the test variables and other explanatory variables with justification of their inclusion in the econometric modelling.

5.2.1 Measurement of stock return synchronicity

This study uses the stock price synchronicity framework proposed by Roll (1988) and refined by Morck et al. (2000) as a measure of the extent to which stock returns incorporate market- and industry-wide information. Similar to prior studies (e.g., (Durnev et al., 2003; and Piotroski and Roulstone, 2004), SYNCH is defined as a log transformation of the regression's R-squared metric of firms' weekly stock returns on both contemporaneous and lagged market returns and industry return variables. In this algorithm, lower (higher) stock return synchronicity exhibited by the firm, indicates a relatively greater amount of firm-specific (market-level and industry-level) information capitalised into the stock price. While some view lower stock synchronicity as indicating greater pricing errors, thus representing noisier stock prices (e.g., Campbell et al., 2001; and Xu and Malkiel, 2003), an increasing body of research provides supporting evidence for the informational interpretation of using stock return synchronicity as an estimate of the relative amount of firm-specific information (e.g., Brockman and Yan, 2009; Durnev et al., 2004; Durnev et al., 2003; Grewal et al., 2017; Jin and Myers, 2006; and Li et al., 2015). Specifically, to construct the synchronicity measure[6], this study firstly estimates a firm's weekly returns using the following regression model modified by Piotroski and Roulstone (2004):

$$RET_{i,w} = \alpha + \beta_1 MKTRET_{w-1} + \beta_2 MKTRET_w + \beta_3 INDRET_{w-1} + \beta_4 INDRET_w + \varepsilon_{i,t}, \quad (1)$$

[6] For a robustness check, this study also uses an alternative proxy, idiosyncratic volatility, to measure the firm-specific component of stock returns.

where $RET_{i,w}$ is firm i's return for week w; $MKTRET_w$ is the value-weighted market return for week w; $INDRET_w$ is the industry value-weighted return of all firms for week w using the same two-digit SIC code with firm i's return excluded to avoid any spurious correlation. As suggested by Dimson (1979), lagged market and industry returns are included to control for the potential nonsynchronous effect of trading by informed participants on the timing of information impounded into stock prices. To obtain the R-squared value for each firm-year, the regression requires a minimum of 40 weekly observations from the Datastream database.

Secondly, following Morck et al. (2000), the firm's stock return synchronicity is defined as:

$$SYNCH_{i,t} = \log\left(\frac{R^2_{i,t}}{1-R^2_{i,t}}\right), \tag{2}$$

where $R^2_{i,t}$ is the R-squared value obtained from estimating Equation (1) for firm i in year t. The log transformation allows an R-squared statistic bounded by zero and one to be transformed into a continuous variable ranging from negative to positive infinity.

Specifically, this study adopts the following econometric model to examine the effect of a firm's carbon performance on firm-specific information:

$$\begin{aligned} SYNCH_{i,t} = {} & \alpha + \beta \times CARBON_{i,t} + \sum_{j=1}^{N} \gamma_j \times Controls^{j}_{i,t} \\ & + \sum_{k=1}^{M} \delta_k \times CountryIndicator^{k}_{i,t} + \sum_{p=1}^{T} \theta_p \times IndustryIndicator^{p}_{i,t} \\ & + \sum_{q=1}^{9} \vartheta_q \times YearIndicator^{q}_{i,t} + \varepsilon_{i,t}, \end{aligned} \tag{3}$$

where the dependent variable, SYNCH, is the stock return synchronicity constructed from weekly returns and the subscripts i and t represent the firm and the year, respectively; CARBON represents the firm's carbon performance based on its historical emission information verified and reported via the European Union Transaction Log under the EU_ETS. In order to capture other potential influences on stock price synchronicity commonly identified in the prior literature, a set of firm-specific and industry-level variables are included in the model as controls. These variables include firm size (SIZE), leverage (LEV), market to book ratio (MB), earnings volatility (ROAVOL), internal firm diversification (DIVERS), systematic volatility in market returns (LNSYSVOL) and the number of firms in each industry (LNNIND).

5.2.2 Measurement of test variables

The procedure for aggregating the emission data to the ultimate parent-firm level is outlined in Chapter 4. This study uses two constructs to measure the corporate carbon performance in order capture both emission intensity (CO2) and future carbon risk profile (CO2PRO). For each firm-year observation, carbon intensity (CO2) is the firm's total carbon emissions scaled by total revenue. The mean carbon intensity by industry reported in Chapter 4 indicated a significant variation in the propensity of carbon emissions generated in various industry sectors. Accordingly, in this study CO2 is then transformed into a decile rank variable of carbon risk profile (CO2PRO) based on an industry-year panel adjustment developed in the literature (e.g., Clarkson et al., 2011; and Clarkson et al., 2015). While CO2 provides an absolute measure of carbon risk profile, CO2PRO captures the firm's carbon risk profile relative to its industry peers. If a higher CO2 (CO2PRO) reduces the amount of firm-specific information in share prices then returns would be more synchronous with industry- and market-wide indicators. Therefore β is expected to be positive.

5.2.3 Other explanatory variables

To capture the influence of other potential firm characteristics on firm-specific information, the following control variables commonly identified from prior related empirical evidence on the synchronicity of stock returns are included in the multivariate regression analyses:

Firm size (SIZE): Prior literature has found firm size is positively related to various dimensions of a firm's information environment, including media publicity and a greater demand for information from a larger number of shareholders. As more public information is likely to be available for larger firms, firm size is usually included to control for the firm-specific information environment (Easley et al., 2002). Empirically, Roll (1988) observes a positive association between firm size and the R-squared value from a market model, implying more market-wide information is impounded in larger firms' stock prices. Furthermore, higher stock return synchronicity can arise for larger firms because they may signal macro-economic trends in the market (Piotroski and Roulstone, 2004) and the stock prices of large firms are more likely to mirror market returns (Chan and Chan, 2014). SIZE is defined as the natural logarithm of the market value of equity at the end of the fiscal year. As more market-wide information is likely to be incorporated in larger firms' stock prices, higher stock return synchronicity is expected.

Firm leverage (LEV): A firm's leverage is used to take account of the capital structure of the firm. Prior studies suggest that cross-sectional variation in stock return volatility increases with leverage. Rajgopal and Venkatachalam (2011) argue that the higher probability of financial distress for a highly leveraged firm may result in more volatile stock returns. Alternatively, Hutton et al. (2009) suggest that firms with higher leverage may be less sensitive to macroeconomic movements as a result of shifting risk from stockholders to debtholders, thus reducing synchronicity. LEV is measured as the book value of total liabilities scaled by total assets at the beginning of the year.

Earnings volatility (ROAVOL): As more volatile earnings produce more firm-specific information, firm-level variation is less likely to be influenced by the market and industry-level trends (Chan and Hameed, 2006). Following Piotroski and Roulstone (2004), earnings volatility is measured as the standard deviation of the firm's net income before extraordinary items scaled by the average total assets in the past 3 years inclusive of the current year. As volatility in a firm's earnings is expected to be associated with increased firm-specific variation and less by market- and industry-wide influence, ROAVOL is expected to be negatively correlated with SYNCH (Boubaker et al., 2014).

Growth opportunity (MB): Gul et al. (2010), among others, observe that market-to-book value is negatively associated with return synchronicity, suggesting stock prices of firms with higher growth opportunity exhibit more firm-specific information. Accordingly, growth potential, measured as the log of the market value of total equity divided by its book value, is also included as a control variable. Because firms with greater growth opportunities are more likely to be subjected to firm-specific uncertainties and greater idiosyncratic volatility (Pástor and Veronesi, 2003), MB is expected to be negatively correlated with SYNCH (Hutton et al., 2009).

Industry structure (LNNIND): The structure of the industry is expected to influence the information environment through a reflection of industry-level information. Boubaker et al. (2014) show that industries with fewer firms experience higher levels of stock price synchronicity, suggesting that the returns of firms operating in a more concentrated industry are more synchronous with market- and industry-wide variations. Similarly, Piotroski and Roulstone (2004) argue that the interdependency of firm returns is likely to increase when there are fewer competitors in an industry using the example of an oligopoly versus a competitive market. Information about one firm may serve as a leading indicator for other firms when the industry has fewer participants. Thus the returns of the remaining firms are likely to be correlated with the leader's returns because of the intra-industry transfer of information. LNNIND is calculated using the average number of constituents in the calculation of the weekly industry return index to which the firm belongs. Following Durnev et al. (2003), LNNIND is included in the econometric model to control for the divergence in synchronicity because of differences in industry size. The sign on LNNIND is predicted to be negative in the regression model.

Internal firm diversification (DIVERS): Firms diversifying their operations through geographic segmentation may be less affected by macroeconomic shifts in their primary location. Hence, firms' aggregate performance may be less likely to reflect market-wide information that manifests in less synchronous stock prices (Piotroski and Roulstone, 2004). Conversely, Roll (1988) argues that the performance of more diversified firms approximates that of a diversified portfolio that has greater exposure to systematic market risks, thereby leading to more synchronous stock prices. Following Li et al. (2015), the proxy utilised in this study for firm diversification, DIVERS, is coded to one if the firm operates a foreign subsidiary. Given the equivocal arguments in the previous literature, the sign on DIVERS is not predicted.

Logarithm of systematic volatility (LNSYSVOL): Systematic volatility captures information relating to market-wide uncertainties. As explained by Li et al. (2014) when reconciling the conflicting results in prior literature, the advantage of controlling for systematic volatility is that an increase in the R-squared statistic is ascertained from a decrease of idiosyncratic volatility. Consistent with Chan and Chan (2014), LNSYSVOL is the natural logarithm of systematic volatility computed as the average weekly variance of the difference between the stock return variance and the variance of the error term ($\varepsilon_{i,t}$) from Eq. (1). As systematic volatility increases, the stock price synchronicity, by definition, decreases. Therefore a positive relationship is expected (Li et al., 2014).

As this study involves firms operating in multiple industries across different member states within the European Union, industry and country fixed effects are included to control for potential differences in synchronicity because of industry membership or other cross-national institutional factors. Year fixed effects are also included to account for any systematic time variation.

5.3 Sample and Data

Sample filtering starts from the initial carbon dataset compiled as detailed in the previous chapter using a sample of European listed firms that are regulated under the

EU_ETS from 2006 to 2015. In order to construct the main dependent variable to test the hypothesis, stock return synchronicity (SYNCH), weekly market- and firm-level returns are also collected from the Datastream database. For a firm to remain in the sample, at least 40 weeks of return observations must be obtained to calculate the synchronicity measure and other stock-related variables. Firms with insufficient or missing financial data for constructing the required control variables as specified in Section 5.2.3 were excluded from the sample. To alleviate survivorship bias, this study adopts an unbalanced panel that allows firms to enter and exit the panel.

The final sample for the main analyses comprises 3645 firm-year observations from 570 unique firms. The frequency distribution by industry and year is similar to those reported in the carbon dataset as shown in Table 4.2. Thus, the further data constraints do not alter the composition of the sample. Most observations are from three main industry sectors: basic materials (25.73%), industrials (23.87%) and consumer goods (21.26%). Firm years from these industries in total comprise 70.86% of the sample. The telecommunication industry is the least represented, comprising less than 1% of the sample. For the sensitivity analyses, firms operating in the financials sector (i.e., Standard Industrial Classification (SIC) Code=8000) are excluded because of heavy regulation and different accounting rules that make the financial variables less comparable to those of other firms. In addition, Utilities (SIC Code=7000) are excluded because they are subject to different financial reporting regulations.

5.4 Descriptive Statistics and Univariate Results

This section provides the descriptive statistics for the information flow variables, carbon variables and the firm-specific characteristics as well as the univariate correlation of the variables used in the multivariate regression analyses.

Table 5.1 presents the summary statistics of the key measures of interest for this study. The final sample contains 3645 firm-year observations for which the requisite data could be obtained to conduct the analyses. The first two information flow variables are important constructs in this study since they manifest the relative distribution of firm-specific information capitalised into stock prices. Consistent with a widely observed weak relationship between firm stock returns and general market and industry movements (low R-Square) in prior literature, the mean and median R-Square for regressions estimated using Eq. (1) are 0.397 and 0.388, respectively, with a standard deviation of 0.208. The dependent variable, stock return synchronicity (SYNCH), has a mean (median) of -0.543 (-0.455), reflecting a lower response to market and industry information compared with firm-specific information. The standard deviation of 1.10 indicates considerable cross-sectional variation in stock return synchronicity. Further, the average stock return synchronicity for the sample firms is higher than the measure reported in Piotroski and Roulstone (2004) using US market data. This is consistent with the differences in the trading environments that have been documented, in general, at country level. In a cross-country study of differences in stock return synchronicity, Morck et al. (2000) observe consistently lower synchronicity for US stocks than for other countries and attribute this systematic difference to stronger government protection of property rights in the US.

Table 5.1. Descriptive statistics

Measures	Mean	Standard Deviation	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile
Information Flows Measure							
R-Square	0.397	0.208	0.077	0.232	0.388	0.551	0.747
SYNCH	-0.543	1.100	-2.486	-1.199	-0.455	0.204	1.083
Carbon Intensity Measure							
CO2	0.094	0.186	0.000	0.003	0.013	0.090	0.517
CO2 (Deficit)	0.109	0.208	0.000	0.002	0.011	0.104	0.574
CO2 (Surplus)	0.088	0.175	0.000	0.003	0.013	0.082	0.482
Firm and Industry Characteristic							
SIZE	15.242	2.061	11.484	13.956	15.383	16.741	18.399
ROAVOL	0.040	0.045	0.006	0.016	0.029	0.049	0.103
LEV	0.672	0.316	0.328	0.519	0.651	0.780	0.913
MB	0.457	0.908	-0.827	0.016	0.471	0.952	1.683
LNNIND	5.258	0.693	4.243	4.685	5.459	5.984	6.170
GEOSEG	3	2	2	2	2	4	7
LNSYSVOL	-0.540	1.390	-3.009	-1.091	-0.265	0.337	1.043

Notes: This table describes the statistics for the key measures constructed for this study. The sample contains 3645 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. R-Square is the coefficient of determination from the firm-year estimation obtained from an augmented market model as specified in Eq. (1). The dependent variable, SYNCH, is defined as a log transformation of R-Square statistic calculated as $\log\left(R^2/\left(1-R^2\right)\right)$. CO2 represents the carbon intensity measured as the verified emissions of a firm scaled by sales revenue (tonnes/$000), where verified emissions is the aggregated annual emissions at the listed controlling-entity level from facility-level emission data verified and reported in the European Union Transaction Log. SIZE is the log of market capitalisation of the firm measured at the end of fiscal year. ROAVOL is calculated as the standard deviation of the firm's ROA in the past three years including the current fiscal year where ROA is the net income before extraordinary items scaled by the average total assets. LEV is the financial leverage measured as ratio of the book value of total liabilities to total assets at the beginning of the year. MB is the natural log of the ratio of the market value of equity to the book value of equity, measured at the end of fiscal year. LNNIND is the log of the average number of firms in each industry by 2-digit SIC code used to calculate the weekly industry index in Eq. (1). GEOSEG is measured as the number of operating geographic segments by a firm in a different registry as reported in the European Union Transaction Log. LNSYSVOL is the log of the firm's systematic volatility measured by the variance of the difference between stock return variance and the variance of the error term ($\varepsilon_{i,t}$) from Eq. (1).

Further, there is considerable variation in the mean stock return synchronicity between EU member states in this study. Hence, beyond the differences between countries as documented in previous studies, variations in SYNCH within a country represent the cross-sectional economic differences and the relative distribution of information flows in stock prices.

Regarding the carbon emissions profile of firms within the sample, the mean (median) value for carbon intensity (CO2) is 0.0941 (0.0129). Therefore, firms in the final sample emit, on average, 0.0941 tonnes of Scope 1 GHG emissions per $1000 of sales. There is also considerable cross-sectional variation in CO2, with the 5th to 95th percentile ranging from 0.0003 to 0.5173 tonnes per $1000 of sales.

The next two rows of Table 5.1 provide statistics for the sample partitioned into firms with a surplus (2544 firm-year observations) and a deficit (1101 firm-year observations) in their allowance balance account. The surplus group has a lower mean CO2 of 0.0878 than the 0.1085 for the deficit group (the mean difference of -0.0207 is significant at 1% level). Consistent with the resource-dependence theory, carbon efficient firms are more likely to accumulate a surplus allowance account substantiating over-compliance with the acceptable emissions regulated by the EU_ETS, which is an asset to the firm. The proportion of the surplus group in this study is somewhat greater than that reported by Clarkson et al. (2015) for their sample over 2006-2009. This difference may be explained by the extension of the sample period and the manual identification of the ultimate parent firm that enabled the inclusion of more low-emitting and comparatively larger firms into this study. Also, there is a general decreasing trend in CO2 during the sample period. This is potentially due to the increasing intensity of regulation, which was implemented as a three-phase program during the sample period.

The control variables illustrate that the sample also comprises both small and large firms (with a mean and median for SIZE of 15.242 and 15.383, respectively, ranging from 11.484 at the 5th percentile to 18.399 at the 95th percentile) and low and high leveraged firms (mean and median for LEV of 0.672 and 0.651, respectively, ranging from 0.328 at the 5th percentile to 0.913 at the 95th percentile). These firms, on average, operate multiple geographic segments (median and standard deviation for GEO of 2 and 2.21, respectively, reaching to 4-segments operated in a foreign country at the upper quartile). They generally engage in industry sectors with numerous competitors (mean and standard deviation for LNNIND of 5.258 and 0.693, respectively) and appear to have a reasonable level of volatility in their earnings (mean and standard deviation for ROAVOL of 0.040 and 0.045, respectively). LNSYSVOL, a portion of market-wide uncertainties, displayed considerable cross-sectional variation as revealed by the standard deviation and inter quartile ranges, reflecting the observed differences in SYNCH attributable to market uncertainties as a result of the fundamentals underlying each firm. The inter-quartile boundary for MB ranges from 0.016 at the lower quartile to 0.952 at the upper quartile indicate that the sample firms include both value and growth firms. Here, the untabulated mean by year reveals that the mean MB also fluctuated during the sample period with the two lowest values of 0.1298 and 0.2129 observed in 2009 and 2012, respectively. This corresponds to the consequence of the global financial crisis and the Eurozone crisis, which erupted late 2009 and intensified subsequently in 2012, resulting in a substantial decrease in the market value of firms. Similarly, there was a sudden substantial increase in SYNCH from a value of -0.7803 in 2008 to -0.1306 in 2009, reaching its highest in 2012 with a positive value of 0.1785, suggesting stock prices are more synchronous with the markets during a macro economic downturn.

Table 5.2 presents the results from univariate analyses. Panel A reports the Pearson correlation matrix among the key variables of interest. The dependent variable SYNCH is positively correlated with CO2, suggesting that stock prices are more synchronous with the market-wide information as the emission propensity increases. Further, the positive correlation between CO2 and LNSYSVOL is statistically significant at the 1% level, implying carbon-intensive firms are more sensitive to market-wide uncertainties. Moreover, the positive correlation between CO2 and ROAVOL indicates that firms with higher emission intensity have more volatile earnings. This is consistent with arguments in the environmental literature that suggest that carbon intensity has a material impact on firms' profitability through operation costs and exposure to the price of carbon (e.g., Labatt and White, 2007). Collectively, as firms' carbon risks increase so do uncertainties about their financial performance. As predicted, LNSYSVOL is positively and highly correlated with SYNCH (ρ=0.673), indicating that systematic volatility is a major driver of variations in the SYNCH measure by construction. This provides a preliminary indication that not controlling for the covariance among LNSYSVOL, the main variable of interest, and SYNCH, may yield a potentially biased estimate in the regression analyses.

Table 5.2. Correlation matrix and univariate results

Panel A: Pearson correlation matrix

	SYNCH	CO2	SIZE	ROAVOL	LEV	MB	LNNIND	DIVERS	LNSYSVOL
SYNCH	1								
CO2	0.037**	1							
SIZE	0.356***	-0.205***	1						
ROAVOL	-0.045**	0.060***	-0.189***	1					
LEV	0.025	-0.031*	0.040**	-0.091***	1				
MB	-0.002	-0.144***	0.441***	-0.032*	0.130***	1			
LNNIND	-0.032*	-0.195***	-0.081***	-0.096***	0.151***	-0.060***	1		
DIVERS	0.245***	0.064***	0.410***	-0.041**	0.023	0.064***	-0.045**	1	
LNSYSVOL	0.673***	0.077***	0.061***	0.062***	0.063***	-0.071***	0.029*	0.142***	1

Panel B: Univariate results of SYNCH between the highest and lowest decile of firms' carbon intensity (CO2)

SYNCH	Mean	Standard Deviation	5^{th} Percentile	25^{th} Percentile	Median	75^{th} Percentile	95^{th} Percentile
CO2 (Top Decile)	-0.442	1.155	-2.425	-1.164	-0.368	0.294	1.302
CO2 (Bottom Decile)	-0.591	1.065	-2.491	-1.214	-0.525	0.091	1.056
Wilcoxon Z test	**2.024****						
p–value	**(0.0430)**						

Notes: Panel A of this table reports the Pearson correlation matrix among the variables used in the regression analyses. The sample contains 3645 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. SYNCH is defined as a log transformation of R-Square statistic obtained from estimating Eq. (1) as $[\log(R^2/(1-R^2))]$. CO2 represents the carbon intensity measured as the verified emissions of a firm scaled by sales revenue (tonnes/\$000), where verified emissions is the aggregated annual emissions at the listed controlling-entity level from facility-level emission data verified and reported in the European Union Transaction Log. SIZE is the log of market capitalisation of the firm measured at the end of fiscal year. ROAVOL is calculated as the standard deviation of the firm's ROA in the past three years including the current fiscal year where ROA is the net income before extraordinary items scaled by the average total assets. LEV is the financial leverage measured as ratio of the book value of total liabilities to total assets at the beginning of the year. MB is the natural log of the ratio of the market value of equity to the book value of equity, measured at the end of fiscal year. LNNIND is the log of the average number of firms in each industry by 2-digit SIC code used to calculate the weekly industry index in Eq. (1). DIVERS denotes a dummy variable equal to one if the firm operates more than one geographic segments (GEOSEG) as reported in the European Union Transaction Log. LNSYSVOL is the log of a firm's systematic volatility measured by the standard deviation of the difference between stock return variance and the variance of the error term ($\varepsilon_{i,t}$) from Eq. (1). The univariate result presented in Panel B is the Wilcoxon Z test for the difference in mean values of SYNCH between the top and bottom decile of firms' CO2; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels (two-tailed), respectively.

As shown in Table 5.2, SYNCH is positively correlated with SIZE, suggesting larger firms have more synchronous prices that co-move with market returns. This reflects a systematic variance in the information environment if SIZE is a proxy for the amount of publicly available information following Brockman and Yan (2009) and hence more market-wide information (less firm-specific information) is capitalised into the stock prices of larger firms. The direction of the pair-wise correlations are also consistent with the literature. In general, these correlations lend preliminary support to the theoretical predictions. The inclusion of these measures in regression models does not introduce multicollinearity issues as indicated by the variance inflation factors, which all are below two (Hair et al., 1998; Gujarati, 2004).

Panel B reports the mean difference of SYNCH between the lowest and the highest intra-industry decile of carbon intensity. The synchronicity measure is lower for firm years within the bottom decile of CO2 within industry and the difference is statistically significant at the 5% level. Thus more firm-specific information has been incorporated into stock prices when firms demonstrate leadership in reducing their carbon intensity relative to industry peers. However, these correlations should be interpreted carefully because they do not control for differences underlying each firm’s operations. Hence, the next section investigates the relationships in the presence of other firm characteristics postulated to influence stock return synchronicity.

5.5 Empirical Results

This section investigates whether the carbon performance of a firm influences the relative flow of firm-specific, industry- and market-level information in prices reflected in the stock return synchronicity, by estimating the regression model specified in Eq. (3).

Consistent with previous studies (e.g., Chen and Gao, 2012; Clarkson et al., 2008; and Clarkson et al., 2013), this study examines the emission profile of a firm using the carbon intensity (CO2) measured as annual historical emissions scaled by sales revenue. Additionally, this study infers the carbon risk profile of a firm using an annual intra-industry decile rank of CO2 (CO2PRO). The dependent variable is stock return synchronicity (SYNCH).

Table 5.3 presents the multivariate results using alterative sets of explanatory variables based on a pooled ordinary least squares (OLS) regression of the entire sample with the standard errors corrected for clustering at the firm level to ensure the robustness of results (Petersen, 2009). Results of the measure of carbon intensity (CO2) are presented in the first three columns. Results of the measure of carbon risk profile (CO2PRO) are presented in columns four to six.

Table 5.3. Regression results for stock return synchronicity

Independent variable	Predicted sign	Stock return synchronicity						Economic impact (Est. (3))
		Est. (1)	Est. (2)	Est. (3)	Est. (4)	Est. (5)	Est. (6)	
CO2	+	0.322***	0.351***	0.300***				0.056
		(<0.001)	(<0.001)	(<0.001)				
CO2PRO	+				0.015***	0.025***	0.023***	
					(0.001)	(<0.001)	(<0.001)	
SIZE	+	0.175***	0.196***	0.191***	0.177***	0.202***	0.201***	0.394
		(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	
ROAVOL	–			-1.047***			-1.034***	-0.047
				(0.003)			(0.005)	
LEV	+/–			-0.089			-0.081	-0.028
				(0.208)			(0.238)	
MB	–			-0.046***			-0.056***	-0.042
				(0.010)			(0.002)	
LNNIND	–			-0.404***			-0.369***	-0.280
				(<0.001)			(<0.001)	
DIVERS	+/–			0.033			0.020	0.002
				(0.141)			(0.383)	
LNSYSVOL	+	0.513***	0.480***	0.481***	0.515***	0.479***	0.479***	0.669
		(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	
Intercept		-2.964***	-3.803***	-1.856***	-2.888***	-3.692***	-1.968***	
		(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	
Year, industry and country fixed effect		No	Included	Included	No	Included	Included	
Adj R-sqr		0.5553	0.7141	0.7189	0.5538	0.7147	0.7197	
Prob > F		(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	

Notes: This table presents regression results for a sample of 3645 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, SYNCH, is defined as a log transformation of R-Square statistic [$\log\left(R^2/\left(1-R^2\right)\right)$] obtained from estimating Eq. (1). The main test variables are CO2 and CO2PRO. CO2 represents the carbon intensity measured as the verified emissions of a firm scaled by sales revenue (tonnes/$000), where verified emissions is the aggregated annual emissions at the listed controlling-entity level from facility-level emission data verified and reported in the European Union Transaction Log. CO2PRO is an industry-year decile rank of the firm's CO2. SIZE is the log of market capitalisation of the firm measured at the end of fiscal year. ROAVOL is calculated as the standard deviation of the firm's ROA in the past three years including the current fiscal year where ROA is the net income before extraordinary items scaled by the average total assets. LEV is the financial leverage measured as ratio of the book value of total liabilities to total assets at the beginning of the year. MB is the natural log of the ratio of the market value of equity to the book value of equity, measured at the end of fiscal year. LNNIND is the log of the average number of firms in each industry by 2-digit SIC code used to calculate the weekly industry index in Eq. (1). DIVERS denotes a dummy variable equal to one if the firm operates more than one geographic segments (GEOSEG) as reported in the European Union Transaction Log. LNSYSVOL is the log of a firm's systematic volatility measured by the variance of the difference between stock return variance and the variance of the error term ($\varepsilon_{i,t}$) from Eq. (1). All results are from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included where indicated; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels (two-tailed), respectively.

The first column of Table 5.3 presents the results of the baseline model for comparison when SYNCH is regressed on CO2 along with firm size (SIZE) and systematic volatility (LNSYSVOL). In line with the correlation results, the coefficient on CO2 is positive and statistically significant at less than the 1% level, indicating a higher emission intensity of the firm constrains the incorporation of firm-specific information, leading to an increase in stock return synchronicity with more market- and industry-wide information captured in the firms' stock returns. The coefficient for SIZE, which is the proxy for various dimensions of the information environment pertaining to the firm, is significant and positive as expected, indicating the stock prices of larger firms incorporate more industry- and market-wide information than those of smaller firms. This result is consistent with the literature that records a positive relationship between firm size and stock return synchronicity suggesting that stock prices of large firms tend to track the market performance because of a greater amount of publicly available information and their signaling role for macro-economic and industry-wide trends (e.g., Piotroski and Roulstone, 2004; and Roll, 1988). Further, the returns of firms sensitive to market-wide information (LNSYSVOL) are highly synchronised with market and industry returns (0.513, $p<0.001$), consistent with results reported by Li et al. (2014).

Examining the results in the second column, where year, industry and country fixed effects are employed in the model, both the magnitude and significance level of the coefficient on CO2 remain relatively similar to the baseline regression. The results confirm that the cross-sectional differences in SYNCH, as reported in Estimation (1), are not merely attributable to any unobserved time-variant, industry- and/or country-specific variations.

Results based on the full regression specification are presented in the third column where additional firm- and industry-level characteristics are controlled. Consistent with the firm-specific information prediction, the coefficient on CO2 is positive and statistically significant at less than the 1% level, suggesting firms exhibiting a high emission profile have less firm-specific (as opposed to industry- and market-wide) information capitalised into their stock prices. Thus, the hypothesis is supported. The effect of SIZE and LNSYSVOL remain positive and statistically significant at less than the 1% level in the presence of additional controls. In addition, ROAVOL is negatively and significantly associated with SYNCH, indicating that the stock price of firms with higher earnings volatility impounds more firm-specific information, thus reducing the synchronicity. This is consistent with the argument that more private information is available when there is more volatility in firms' fundamentals, assuming a constant flow of public information (Chan and Hameed, 2006). Consistent with Hutton et al. (2009), the estimated coefficient for MB is negative ($p<0.001$), which implies firms with high growth opportunities are likely to be affected by market- and industry-wide trends. In addition, this study finds a negative relationship between LNNIND and SYNCH at less than the 1% significance level. This suggests that when a firm is engaged in an industry with fewer participants, the firm's stock return tends to mirror industry and market returns. The coefficient estimates for LEV and DIVERS are both insignificant at all conventional levels, similar to Boubaker et al. (2014) using a sample of French companies.

In the regression of firms' stock return synchronicity on the carbon risk profile (CO2PRO), the coefficients on CO2PRO are positive and statistically significant at less than the 1% level in all three regression specifications (Estimations (4) to (6)). This further supports the firm-specific information hypothesis, suggesting that the stock price of firms that exhibit leadership in managing their future carbon risk profile captures more firm-specific information, which translates into lower synchronicity. Importantly, this reaffirms that the results are robust to the alternative measure allowing for explicit consideration of the heterogeneity of emission profiles inherent across industry sectors as reported in Chapter 4. Therefore, this addresses the potential concern that CO2 may capture the effect of an omitted variable co-varying with industry-level operations rather than a firm-specific attribute. The coefficients on all other control variables are uniformly in the same direction at significance levels similar to the model using the CO2 measure. Thus, for both of the full regressions (Estimations (3) and (6)), the observed relationships for additional firm characteristics are intuitive and similar to prior studies, indicating that the empirical model is well-specified.

The last column in Table 5.3 compares the economic impact of independent variables from Estimation (3). On average, an increase of one standard deviation in CO2 gives rise to a 5.6% increase in stock return synchronicity, indicating that a firm's carbon intensity has an economically significant effect on synchronicity. LNSYSVOL dominates the effect on synchronicity, which is expected, given that the construction of the measure is a ratio of systematic volatility to idiosyncratic volatility. As noted by Li et al. (2014), failure to control for systematic volatility may confound inferences from changes in SYNCH, to the extent that it is driven by firm-specific information if it co-varies cross-sectionally with the variable of interest. Other than LYSYSVOL, SIZE has the largest economic impact (39.4%) on stock return synchronicity, similar to that observed by Hutton et al. (2009).

A possible issue in pooled OLS regression analyses is that there may be cross-sectional correlation in residuals and therefore OLS standard errors may be biased, potentially resulting in incorrect inferences (Petersen, 2009). To address this potential concern, equations in Table 5.3 are re-estimated including industry and country fixed effects following the two-step approach developed by Fama and MacBeth (1973), which has been widely used in asset-pricing tests to correct for the potential cross-sectional correlation in error terms. More specially, the cross-section of stock return synchronicity is regressed on the variables listed above for each year during 2006-2015. The coefficient estimates presented in Table 5.4 are time-series averages of the parameters from the 10 annual cross-sectional regressions. The Newey and West heteroskedasticity-consistent standard errors (Newey and West, 1987) are used and corrected for autocorrelation at one lag consistent with previous studies (e.g., Boubaker et al., 2014; and Jin and Myers, 2006).

The results reported in Table 5.4 are largely consistent with those derived from the earlier pooled regression analyses reported in Table 5.3. The main variables of interest, CO2 and CO2PRO, remain significant at less than the 1% level and have a positive effect on stock return synchronicity in Estimations (2) and Estimation (4), respectively. The estimated coefficient on LEV is negative and significant at the 5% level. This result supports the argument that, as leverage increases, debtholders share more idiosyncratic risks and help to impound more firm-specific information into share prices leading to a lower synchronicity measure (Hutton et al., 2009).

Table 5.4. Regression results for stock return synchronicity (Fama-Macbeth (1973) approach)

Independent variable	Predicted sign	Stock return synchronicity				Economic impact (Est. (2))
		Est. (1)	Est. (2)	Est. (3)	Est. (4)	
CO2	+	0.501***	0.356***			0.066
		(<0.001)	(<0.001)			
CO2PRO	+			0.023***	0.022***	
				(<0.001)	(<0.001)	
SIZE	+	0.191***	0.190***	0.194***	0.199***	0.392
		(<0.001)	(<0.001)	(<0.001)	(<0.001)	
ROAVOL	–		-1.372***		-1.379***	-0.062
			(0.002)		(0.002)	
LEV	+/–		-0.157**		-0.137**	-0.050
			(0.010)		(0.018)	
MB	–		-0.039*		-0.050**	-0.035
			(0.058)		(0.025)	
LNNIND	–		-0.143***		-0.201***	-0.100
			(<0.001)		(<0.001)	
DIVERS	+/–		0.034		0.023	0.002
			(0.223)		(0.401)	
LNSYSVOL	+	0.490***	0.489***	0.491***	0.484***	0.680
		(<0.001)	(<0.001)	(<0.001)	(<0.001)	
Intercept		-3.261***	-2.350***	-3.150***	-2.065***	
		(<0.001)	(<0.001)	(<0.001)	(<0.001)	
Year fixed effect		No	No	No	No	
Industry and country fixed effect		Included	Included	Included	Included	
Avg R-sqr		0.6644	0.6786	0.6598	0.6778	
Prob > F		(<0.001)	(<0.001)	(<0.001)	(<0.001)	

Notes: This table reports the regression results for stock return synchronicity using the Fama-Macbeth (1973) approach for a sample of 3645 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, SYNCH, is defined as a log transformation of R-Square statistic [$\log\left(R^2/(1-R^2)\right)$] obtained from estimating Eq. (1). The main test variables are CO2 and CO2PRO. CO2 represents the carbon intensity measured as the verified emissions of a firm scaled by sales revenue (tonnes/$000), where verified emissions is the aggregated annual emissions at the listed controlling-entity level based on facility-level emission data verified and reported in the European Union Transaction Log. CO2PRO is an industry-year decile rank of the firm's CO2. SIZE is the log of market capitalisation of the firm measured at the end of fiscal year. ROAVOL is calculated as the standard deviation of the firm's ROA in the past three years including the current fiscal year where ROA is the net income before extraordinary items scaled by the average total assets. LEV is the financial leverage measured as ratio of the book value of total liabilities to total assets at the beginning of the year. MB is the natural log of the ratio of the market value of equity to the book value of equity, measured at the end of fiscal year. LNNIND is the log of the average number of firms in each industry by 2-digit SIC code used to calculate the weekly industry index in Eq. (1). DIVERS denotes a dummy variable equal to one if the firm operates more than one geographic segments (GEOSEG) as reported in the European Union Transaction Log. LNSYSVOL is the log of a firm's systematic volatility measured by the variance of the difference between stock return variance and the variance of the error term ($\varepsilon_{i,t}$) from Eq. (1). All results are based on the heteroskedasticity and autocorrelation consistent Newey and West (1987) standard errors corrected for autocorrelation at one-order lag. Year, Industry and country fixed effect are included where indicated; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels (two-tailed), respectively.

Taken together, the main results tabulated in Table, 5.3 and 5.4 are robust to alternative specifications and consistently find a positive association between the carbon performance and stock return synchronicity, statistically significant at less than the 1% level. These results collectively provide evidence that stock returns of firms with a high emission profile and a high carbon risk profile within an industry capture less firm-specific flow of information as compared with flows of industry- and market-wide information, translating into a higher stock return synchronicity. In addition to supporting the relevance of firms' historical emission information to market valuation, as documented in Clarkson et al. (2015), Griffin et al. (2017) and Matsumura et al. (2014), this study extends that stream of research by providing further evidence that a firm's historical carbon performance is also assessed by capital market participants as idiosyncratic to the firm, influencing the impounding of firm-specific information into share prices. More importantly, it provides evidence that market participants also incorporate more firm-specific information when a firm's carbon intensity is lower relative to industry rivals. This is consistent with the argument in previous environmental studies that such a relative advantage in environmental management represents a firm-specific attribute (e.g., Clarkson et al., 2011; Hart 1995; Hart and Ahuja 1996; Mishra and Modi 2013; and Russo and Fouts 1997).

5.6 Further Analyses

This section provides additional considerations related to the interpretation of the results. The first subsection investigates whether the balance of the emission allowance provides incremental firm-specific information in addition to a carbon metric. The second subsection explores whether carbon performance explains additional stock price dynamics. More specifically, it explores whether the relationship between the carbon metrics and the emission allowances balance influences the stock return volatility decomposed into systematic volatility and idiosyncratic volatility. The third subsection examines whether a carbon metric influences the negative skewness of firms' return distributions, namely, firm-specific stock price crash risk.

5.6.1 The effect of the balance of an emission allowance account

A prominent feature of an ETS is that carbon allowances are tradable instruments where surplus allowances can be banked. With the objective to induce cost effective reduction of carbon emissions, the trading mechanism facilitates an efficient equilibrium where the carbon price is equal to the lowest marginal abatement cost (Egenhofer, 2007). Therefore, this regulatory setting suggests the emergence of two carbon management stereotypes: carbon-efficient firms that over-comply with emission allocations through permanent mitigation resulting in accumulating surplus allowance; and carbon-intensive firms that manage their emission profile using emission allowances (Bebbington and Larrinaga-González 2008; Bianchi 1995; Christmann 2000; Clarkson et al. 2004; IPCC; 2007).

One possible reason for a lower proportion of firm-specific information capitalised in the stock prices of carbon-intensive firms is their carbon management stereotypes. Accordingly, the additional allowance account details provide an opportunity to examine whether over-compliance with an environmental program reflected in a surplus allowance account provides more firm-specific information. Empirically, Clarkson et al. (2015) observe that investors assess a firm's latent emission liability conditional on the allowance position in the absence of an accounting standard. Furthermore, previous literature suggests over-compliance with current environmental standards reduces information asymmetry (e.g., Chen and Gao, 2012; and Clarkson et al., 2011). The surplus of allowances allocated under the EU_ETS over the firm's carbon emissions is used as a proxy for the firm's over-compliance with acceptable carbon emissions. Thus, a carbon metric conditional on an allowance surplus is expected to provide more firm-specific information, leading to lower stock return synchronicity.

To examine the impact of the balance of an emission allowance account on the relationship between carbon performance and stock return synchronicity, the sample is first partitioned into two groups based on whether they have accumulated an allowance deficit (Deficit) or surplus (Surplus).

Results for the test of whether stock return synchronicity is significantly different between the deficit and surplus groups using a joint seemingly unrelated regression estimation are presented in columns one to four, Table 5.5. Test results for equivalence between the two groups are reported at the bottom of the table. Estimations (1) and (2) reveal that the coefficient estimates on CO2 are positive and significant for both deficit and surplus allowance groups. Consistent with the primary results, the emission intensity deters the impounding of firm-specific information, resulting in more synchronous stock returns with industry- and market-wide information.

This effect persists indifferently between the deficit and surplus groups albeit with a lower coefficient on CO_2 for the surplus group. A comparison of parameter estimates on CO_2 from the two groups (χ^2=0.05 p-value=0.825) indicates the difference in magnitude is not statistically significant. This suggests surplus allowances do not alleviate the limit of firm-specific information incorporated into stock returns of carbon-intensive firms. Repeated in Estimations (3) and (4) is a comparison of coefficient estimates on CO2PRO, as reported in the Chi-square test statistic (χ^2=0.00 p-value=0.960). Similarly, the estimate is again lower for the surplus group compared with the deficit group but the difference is not significant at conventional levels, suggesting the heightened synchronicity from a high intra-industry carbon risk profile is not significantly different between deficit and surplus groups.

Recent developments in environmental management theory suggest firms pursuing proactive environmental strategies imply efficient integration of resources and sustainable competitive advantage unique to the firm (e.g., Christmann, 2000; Hart, 1995; and Porter and van der Linde, 1995). Specifically, the natural-resource-based view of the firm predicts that a proactive carbon management strategy does not provide equal advantage to all firms because the mechanisms under which such a strategy can be achieved underlie superior management capabilities (e.g., Hart and Ahuja, 1996; Russo and Fouts, 1997; and Sharma and Vredenburg, 1998).

Table 5.5. Regression results for stock return synchronicity partitioned into deficit and surplus groups by allowance balance

	Stock return synchronicity							
	Est. (1)	Est. (2)	Est. (3)	Est. (4)	Est. (5)	Est. (6)	Est. (7)	Est. (8)
Independent variable	Deficit	Surplus	Deficit	Surplus	High Deficit	High Surplus	High Deficit	High Surplus
CO2	0.322***	0.293***			0.836**	0.204**		
	(0.005)	(<0.001)			(0.016)	(0.017)		
CO2PRO			0.025***	0.024***			0.193***	0.023***
			(0.001)	(<0.001)			(<0.001)	(0.002)
SIZE	0.192***	0.192***	0.202***	0.203***	0.130***	0.213***	0.158***	0.221***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(0.001)	(0.000)	(<0.001)	(0.000)
ROAVOL	-2.323***	-0.880***	-2.244***	-0.873***	-2.406	-0.841***	-2.842	-0.794***
	(0.001)	(<0.001)	(0.001)	(<0.001)	(0.258)	(0.002)	(0.170)	(0.004)
LEV	-0.256***	-0.061*	-0.240***	-0.053	-0.392**	-0.052	-0.357**	-0.046
	(0.004)	(0.083)	(0.007)	(0.131)	(0.036)	(0.193)	(0.050)	(0.247)
MB	-0.037	-0.050***	-0.044*	-0.064***	-0.145	-0.094***	-0.205**	-0.104***
	(0.131)	(0.003)	(0.077)	(<0.001)	(0.101)	(0.000)	(0.020)	(0.000)
LNNIND	-0.266	-0.439***	-0.228	-0.392***	-2.104	-0.562**	-1.880	-0.526
	(0.106)	(<0.001)	(0.167)	(0.001)	(0.433)	(0.011)	(0.470)	(0.384)
DIVERS	0.025	0.042	0.022	0.024	0.035	0.006	0.005	-0.010
	(0.583)	(0.139)	(0.621)	(0.409)	(0.826)	(0.884)	(0.973)	(0.801)
LNSYSVOL	0.478***	0.482***	0.478***	0.480***	0.381***	0.411***	0.357***	0.410***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(0.000)	(<0.001)	(0.000)
Intercept	-2.437***	-1.660***	-2.574***	-1.823***	6.446	-1.284	5.691	-1.463
	(0.003)	(0.004)	(0.001)	(0.002)	(0.588)	(0.191)	(0.621)	(0.589)
Subsample comparison of coefficients on CO2/CO2PRO	χ^2=0.05 (p-value = 0.825)		χ^2=0.00 (p-value = 0.960)		χ^2=6.95*** (p-value = 0.008)		χ^2= 9.60*** (p-value < 0.002)	

N	1101	2544	1101	2544	152	417	152	417
Adj R-sqr	0.7326	0.7128	0.7332	0.7139	0.7086	0.7007	0.7257	0.7012
Prob > F	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)

Notes: This table summarises regression results of the subsample analyses of the effect of carbon allowances balance on stock return synchronicity. The carbon allowances balance is used to gauge firms' over-compliance with the EU_ETS under the regulatory setting. The sample contains 3645 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. In the first four columns, the sample was partitioned into two subsamples in accordance with their carbon allowances balance: firms with deficit (Deficit) carbon allowances less than emission and firms with surplus (Surplus) carbon allowances greater than emission. In the last four columns, firms' deficit and surplus carbon allowances ranked at the top two deciles are further classified as high deficit versus high surplus group, respectively. The dependent variable, SYNCH, is defined as a log transformation of R-Square statistic [$\log\left(R^2/\left(1-R^2\right)\right)$] obtained from estimating Eq. (1). The main test variables of interest are CO2 and CO2PRO. CO2 represents the carbon intensity measured as the verified emissions of a firm scaled by sales revenue (tonnes/$000), where verified emissions is the aggregated annual emissions at the listed controlling-entity level based on facility-level emission data verified and reported in the European Union Transaction Log. CO2PRO is an industry-year decile rank of the firm's CO2. SIZE is the log of market capitalisation of the firm measured at the end of fiscal year. ROAVOL is calculated as the standard deviation of the firm's ROA in the past three years including the current fiscal year where ROA is the net income before extraordinary items scaled by the average total assets. LEV is the financial leverage measured as ratio of the book value of total liabilities to total assets at the beginning of the year. MB is the natural log of the ratio of the market value of equity to the book value of equity, measured at the end of fiscal year. LNNIND is the log of the average number of firms in each industry by 2-digit SIC code used to calculate the weekly industry index in Eq. (1). DIVERS denotes a dummy variable equal to one if the firm operates more than one geographic segments (GEOSEG) as reported in the European Union Transaction Log. LNSYSVOL is the log of a firm's systematic volatility measured by the variance of the difference between stock return variance and the variance of the error term ($\varepsilon_{i,t}$) from Eq. (1). All results are from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effects are also included in the regressions; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels (two-tailed), respectively.

In particular, this theoretical framework suggests that holding excess allowances by carbon-efficient firms through permanent mitigation may generate firm-specific competitiveness over industry peers. In contrast, the firm-specific competitiveness does not accrue to carbon-intensive firms merely using emission allowances as instruments to manage the resultant impact of carbon constraints. Overall, while the emission propensity is largely influenced by industry characteristics, the environmental risk management literature suggests to the extent that a higher level of firm-specific information is embodied in firms' carbon management strategy (e.g., Chen and Gao, 2012; Subramaniam et al., 2015; and UNEP Finance Initiative, 2006), more firm-specific information may be captured in stock returns, thus mitigating the positive association between CO2 and SYNCH.

Similar to the method developed by Clarkson et al. (2011) using longitudinal data to infer a proactive strategy, another attempt was made to further partition the sample into progressive firms and regressive firms according to firms' relative allowance position within an industry-year. In a similar vein, this study classifies progressive firms as those whose allowance surplus ranked in the highest two deciles (High Surplus) and regressive firms are classified as those whose allowance deficit ranked in the highest two deciles (High Deficit).

Results for the comparison of coefficients of a carbon metric on stock return synchronicity between the high deficit and high surplus groups are reported in the last four columns of Table 5.5. Using a joint seemingly unrelated regression estimation, as revealed in Estimations (5) to (8), the coefficient estimates on CO2 (CO2PRO) are positive and significant for both high deficit and high surplus groups. Similar to the subsample analyses between deficit and surplus groups, the stock prices of firms with a higher carbon intensity (carbon risk profile) exhibit fewer flows of firm-specific information, leading to a more synchronous stock returns with industry- and market-wide information. It is important to note that the difference in size of the coefficient on CO2 (CO2PRO) between Estimations (5) and (6) [Estimations (7) and (8)] is statistically significant between the high surplus and high deficit groups with a lower amount of firm-specific information consistently being capitalised into stock returns for carbon-intensive firms with high allowance deficit using both CO2 (χ^2 =6.95 p-value=0.008) and CO2PRO (χ^2=9.60 p-value=0.002) as indicated at the bottom of Table 5.5.

Additionally, while the estimate on ROAVOL is negative and statistically significant for the high surplus group, similar to the primary results, the estimate is not significant for the high deficit group. This suggests variations in earnings fundamentals of firms with a proactive carbon management strategy impounds more firm-specific information in their stock prices while the relationship does not persist for regressive firms. The result can be viewed as indirect evidence consistent with previous studies observing a positive relationship between firms' propensity to engage in socially responsible practice and accounting information quality (e.g., Gelb and Strawser 2001; and Kim et al., 2012). However, it should be noted that because of further data constraints in the empirical construct, focusing on these subgroups of progressive and regressive firms with significantly decreased sample size may influence the power of statistical tests and therefore potentially limit the conclusiveness of the results.

Second, and more formally, regression specifications are expanded to include two additional explanatory variables: a dummy variable (CO2SURPLUS) that equals one if the firm accumulates a surplus allowance, and zero, otherwise; and a variable interacting CO2SURPLUS with a carbon metric. Regression analyses estimated using CO2 and CO2PRO as carbon performance metrics are reported in Estimations (1) and (2), Table 5.6. Consistent with the results in the subsample comparison, higher carbon intensity and carbon risk profile significantly reduce the amount of firm-specific information capitalised into stock prices as reflected by an increase in the synchronicity measure; the estimate for the interaction term is not significant at conventional levels.

In Estimations (3) and (4), the comparison is repeated for the classification of firm years between high surplus and high deficit. HSURPLUS equals one if the firm's allowance surplus is within the highest two deciles in an industry-year, or zero if the firm's allowance deficit is within the highest two deciles in a given industry-year. Similar to the results reported in the analyses between progressive and regressive subsamples, while higher emission propensity and carbon risk profile limit the impounding of firm-specific information, a progressive carbon reduction effort signifying permanent mitigation of carbon risks is found to represent incremental firm-specific information, resulting in reduced synchronicity.

Overall, a surplus allowance account does not appear to provide further firm-specific information in addition to the carbon performance measure of a firm. Based on a limited sample, firms pursuing a proactive carbon management strategy have more firm-specific information impounded in their stock prices, mitigating the heightened synchronousness with industry- and market- wide information because of a higher emission profile or carbon risk profile. The next section investigates the effect of a carbon metric on the variation in the components comprising the synchronicity measure to better understand the underlying mechanism.

Table 5.6. Regression results for stock return synchronicity conditioned on allowance surplus

Independent	Stock return synchronicity		Independent	Stock return synchronicity	
variable	Est. (1)	Est. (2)	variable	Est. (3)	Est. (4)
CO2	0.234***		CO2	0.574***	
	(0.006)			(0.001)	
CO2PRO		0.020**	CO2PRO		0.154***
		(0.025)			(0.002)
CO2SURPLUS	-0.030	-0.004	HSURPLUS	0.132	-0.126
	(0.260)	(0.940)		(0.203)	(0.142)
CO2 X CO2SURPLUS	0.094		CO2 X HSURPLUS	-0.375*	
	(0.399)			(0.070)	
CO2PRO X CO2SURPLUS		0.005	CO2PRO X HSURPLUS		-0.131**
		(0.573)			(0.012)
SIZE	0.191***	0.201***	SIZE	0.186***	0.194***
	(<0.001)	(<0.001)		(<0.001)	(<0.001)
ROAVOL	-1.034***	-1.025**	ROAVOL	-1.487	-1.491
	(0.004)	(0.017)		(0.132)	(0.149)
LEV	-0.089	-0.081	LEV	-0.038	-0.037
	(0.209)	(0.250)		(0.512)	(0.514)
MB	-0.046***	-0.057**	MB	-0.044	-0.074
	(0.009)	(0.031)		(0.384)	(0.144)
LNNIND	-0.396***	-0.358*	LNNIND	0.463**	0.497**
	(<0.001)	(0.067)		(0.048)	(0.031)
DIVERS	0.035	0.022	DIVERS	0.068	0.055
	(0.119)	(0.597)		(0.362)	(0.469)
LNSYSVOL	0.481***	0.479***	LNSYSVOL	0.365***	0.359***
	(<0.001)	(<0.001)		(<0.001)	(<0.001)
Intercept	-1.870***	-2.010**	Intercept	-5.700***	-5.576***
	(<0.001)	(0.029)		(<0.001)	(<0.001)
N	3645	3645	N	569	569
Adj R-sqr	0.7189	0.7197	Adj R-sqr	0.7390	0.7419
Prob > F	(<0.001)	(<0.001)	Prob > F	(<0.001)	(<0.001)

Notes: This table presents regression results for stock return synchronicity for a sample of 3645 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, SYNCH, is defined as a log transformation of R-Square statistic $[\log(R^2/(1-R^2))]$ obtained from estimating Eq. (1). CO2 represents the carbon intensity measured as the verified emissions of a firm scaled by sales revenue (tonnes/$000), where verified emissions is the aggregated annual emissions at the listed controlling-entity level based on facility-level emission data verified and reported in the European Union Transaction Log. CO2PRO is an industry-year decile rank of the firm's CO2. CO2SURPLUS is a dummy variable equal to one if the firm has carbon allowances greater than emissions. HSURPLUS is a dummy variable equal to one if the firm has surplus allowances within the highest two decile and zero if the firm's allowance deficit is within the highest two decile in a given industry-year. SIZE is the log of market capitalisation of the firm measured at the end of fiscal year. ROAVOL is calculated as the standard deviation of the firm's ROA in the past three years including the current fiscal year where ROA is the net income before extraordinary items scaled by the average total assets. LEV is the financial leverage measured as ratio of the book value of total liabilities to total assets at the beginning of the year. MB is the natural log of the ratio of the market value of equity to the book value of equity, measured at the end of fiscal year. LNNIND is the log of the average number of firms in each industry by 2-digit SIC code used to calculate the weekly industry index in Eq. (1). DIVERS denotes a dummy variable equal to one if the firm operates more than one geographic segments (GEOSEG) as reported in the European Union Transaction Log. LNSYSVOL is the log of a firm's systematic volatility measured by the variance of the difference between stock return variance and the variance of the error term ($\varepsilon_{i,t}$) from Eq. (1). All results are from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in all models; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels (two-tailed), respectively.

5.6.2 Decomposition of stock return variations

This subsection examines the impact of carbon performance on firms' stock return variations disaggregated into two volatility measures, the market-wide variation (systematic variation) and the firm-specific variation (idiosyncratic variation). Specially, the following regression model is estimated:

$$\begin{aligned} LNSYSVOL/LNIDIOVOL_{i,t} = \alpha &+ \beta_1 \times CARBON_{i,t} + \beta_2 \times CO2SURPLUS_{i,t} \\ &+ \beta_3 \times (CARBON_{i,t} \times CO2SURPLUS_{i,t}) \\ &+ \sum_{j=1}^{N} \gamma_j \times Controls_{i,t}^{j} + \sum_{k=1}^{M} \delta_k \times CountryIndicator_{i,t}^{k} \\ &+ \sum_{p=1}^{T} \theta_p \times IndustryIndicator_{i,t}^{p} \\ &+ \sum_{q=1}^{9} \vartheta_q \times YearIndicator_{i,t}^{q} + \varepsilon_{i,t}, \end{aligned} \quad (4)$$

where LNSYSVOL is the log of systematic variation measured as the variance of the difference between stock return variance and the variance of the residual ($\varepsilon_{i,t}$) in Eq. (1); LNIDIOVOL is the log of idiosyncratic variation measured as the variance of the firm's residuals ($\varepsilon_{i,t}$) obtained from Eq. (1); CARBON denotes variables used to measure firms' carbon performance, namely, CO2 and CO2PRO, as previously defined; and CO2SURPLUS is a dummy variable equal to one if the firm accumulates a surplus allowance and zero otherwise. The econometric model also includes firm size, earnings volatility, leverage, market-to-book ratio, the number of firms operating intra-industry, and firm diversification as control variables, as defined above. In addition, industry, country and year indictors are included to control for any unobservable industry, regime and year fixed effects.

In essence, the measure of stock return synchronicity capturing the proportion of industry- and market-wide variation to firm-specific variation, in an augmented market model, is additively decreasing in idiosyncratic volatility and increasing in systematic volatility. Hence, one possibility for the observed high synchronicity for firms with high carbon intensity is that their emission propensity systematically leads to high co-movement with industry- and market-wide variation. Alternatively, assuming constant systematic volatility, a high carbon profile deters firms' information environment because it reduces return variations underlying firm-specific events, resulting in a more synchronous stock return. Hence, this subsection addresses the issues related to the potential simultaneous covariance between the main variable of interest and the two individual components of return synchronicity, systematic volatility and idiosyncratic volatility. The use of idiosyncratic volatility as an alternative proxy for firm-specific information has been adopted in numerous studies (e.g., Brockman and Yan, 2009; Chen et al., 2012; and Rajgopal and Venkatachalam, 2011) to address concern that the primary results and conclusions are not sensitive to the alternative empirical constructs employed. As noted by Brockman and Yan (2009), idiosyncratic volatility illustrates an absolute measure of firm-specific volatility and complements a relative measure of firm-specific volatility using the synchronicity measure. Researchers in environmental risk management suggest that firms releasing less pollution are inherently less sensitive to price increases and therefore less susceptible to macroeconomic shifts (Sharfman and Fernando, 2008; Stulz, 2003; Thompson, 1967). For example, firms with a more carbon efficient process would be less adversely affected by increases in the cost of carbon or regulatory changes, such as caps on emissions. Hence, β_1 in Eq. (4) is expected to be positively associated with LNSYSVOL. As a second proxy for firm-specific information, idiosyncratic volatility measured as the firm-specific component of returns after controlling for market and industry factors, is predicated to have an inverse relationship with the carbon variables.

Table 5.7 reports in the first two columns the results of regression analyses with systematic volatility as the dependent variable. The first column provides the results using CO2 as a proxy for a firm's carbon performance and the second column provides results using CO2PRO as a proxy for a relative carbon performance within an industry-year. Both regression specifications also include a dummy variable (CO2SURPLUS) to denote whether the firm accumulated a surplus allowance account, and an interaction term between the carbon metric and CO2SURPLUS.

As expected, the coefficients for both CO2 and CO2PRO are positive and statistically significant, providing evidence that firms' high emission propensity increases the covariance of their returns with industry- and market-wide variations, leading to higher systematic volatility. In terms of economic significance based on estimates from Estimation (1), the parameter estimate of 0.256 indicates that, on average, a one standard deviation increase in CO2 results in an increase of 4.76% in logarithm systematic volatility ($0.256 * 0.186 = 0.0476$). The estimates on CO2SURPLUS and the interaction term between CO2SURPLUS and CO2 are positive but insignificant at conventional levels, implying holding excess allowances does not have an effect on the systematic component of firms' stock returns.

Table 5.7. Regression results for volatility components

Independent variable	Systematic Volatility Est. (1)	Systematic Volatility Est. (2)	Idiosyncratic Volatility Est. (3)	Idiosyncratic Volatility Est. (4)
CO2	0.256*		-0.181**	
	(0.070)		(0.036)	
CO2PRO		0.033*		-0.050**
		(0.061)		(0.036)
CO2SURPLUS	0.034	0.137	0.044	0.183
	(0.481)	(0.146)	(0.113)	(0.142)
CO2 X CO2SURPLUS	0.068		0.017	
	(0.703)		(0.888)	
CO2PRO X CO2SURPLUS		0.022		0.033
		(0.223)		(0.146)
SIZE	0.033***	0.061***	-0.194***	-0.209***
	(0.007)	(0.010)	(<0.001)	(<0.001)
ROAVOL	2.684***	2.697***	3.047***	3.073***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)
LEV	0.349**	0.366**	0.297***	0.285***
	(0.011)	(0.020)	(<0.001)	(<0.001)
MB	-0.093**	-0.110	-0.029	-0.019
	(0.019)	(0.184)	(0.263)	(0.460)
LNNIND	-1.904***	-1.846***	0.313***	0.121***
	(0.004)	(0.007)	(<0.001)	(<0.001)
DIVERS	0.170***	0.114	-0.029	-0.007
	(<0.001)	(0.188)	(0.247)	(0.780)
Intercept	-1.511	-1.920	-5.980***	-5.140***
	(0.575)	(0.489)	(<0.001)	(<0.001)
Adj R-sqr	0.4617	0.4667	0.4907	0.4878
Prob > F	(<0.001)	(<0.001)	(<0.001)	(<0.001)

Notes: This table presents regression results for stock return volatility components for a sample of 3645 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable in Estimations (1) and (2), LNSYSVOL, is defined as the log of a firm's systematic volatility measured by the variance of the difference between stock return variance and variance of the error term ($\varepsilon_{i,t}$) from Eq. (1). The dependent variable in Estimations (3) and (4), LNIDIOVOL, is defined as the log of a firm's idiosyncratic volatility measured by the variance of the error term ($\varepsilon_{i,t}$) from Eq. (1). CO2 represents the carbon intensity measured as the verified emissions of a firm scaled by sales revenue (tonnes/$000), where verified emissions is the aggregated annual emissions at the listed controlling-entity level based on facility-level emission data verified and reported in the European Union Transaction Log. CO2PRO is an industry-year decile rank of the firm's CO2. CO2SURPLUS is a dummy variable equal to one if the firm has surplus carbon allowances greater than emissions. SIZE is the log of market capitalisation of the firm measured at the end of fiscal year. ROAVOL is calculated as the standard deviation of the firm's ROA in the past three years including the current fiscal year where ROA is the net income before extraordinary items scaled by the average total assets. LEV is the financial leverage measured as ratio of the book value of total liabilities to total assets at the beginning of the year. MB is the natural log of the ratio of the market value of equity to the book value of equity, measured at the end of fiscal year. LNNIND is the log of the average number of firms in each industry by 2-digit SIC code used to calculate the weekly industry index in Eq. (1). DIVERS denotes a dummy variable equal to one if the firm operates more than one geographic segments (GEOSEG) as reported in the European Union Transaction Log. All results are from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in all models; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels (two-tailed), respectively.

The signs of the coefficients for the control variables are largely consistent with those observed in previous studies (e.g., Chan and Chan, 2014; and Rajpopal and Venkatachalam, 2011). Firms that are larger, or have higher earnings volatility or higher leverage, exhibit more systematic variation in their returns.

Estimations (3) and (4), Table 5.7 replicate the analyses in the first two columns with the dependent variable replaced as idiosyncratic volatility. Consistent with the primary results using stock return synchronicity, the estimated coefficients on both CO2 and CO2PRO are negative and significant, indicating that higher carbon intensity and risk profile reduce the amount of firm-specific information in stock prices. The coefficients for CO2SURPLUS and the interaction are both positive but insignificant. The positive loading observed on both systematic and idiosyncratic variations implies a surplus account potentially contains confounding signals capturing both market- or industry-wide norms and firm characteristics. These results are robust to additional control variables combined with industry, year and country fixed effects.

Overall, the results in Table 5.7 suggest that firms with a high emission profile exhibit more industry- and market-wide (less firm-specific) variation in their stock returns. These findings supplement, with new insights, the growing stream of research investigating the relationship between firms' environmental risk management and market-based firm risks (e.g., Dhaliwal et al., 2011; El Ghoul et al., 2011; Jo and Na, 2012; Metcalf et al., 2016; and Sharfman and Fernando, 2008).

Previous studies in the risk management literature have examined share price movements on environmentally-related events and attempt to predict firm-specific stock price crash risk. The next section builds on this literature to investigate the effect of carbon performance on stock price crash risk.

5.6.3 Stock price crash risk

As documented by previous literature, the distribution of stock returns is aggregately asymmetric, exhibiting more negative skewness than large positive stock price adjustments (e.g., Chen et al., 2001; and Hong and Stein, 2003). Following Chen et al. (2001) and Kim et al. (2014), this study also adopts a euphemistic definition of crash risk as the conditional skewness of return distribution. Crash risk constitutes a specific form of return distribution that is important to asset-pricing, portfolio construction and risk management (Harvey and Siddique, 2000).

A number of studies have provided a theoretical framework to relate the firm-specific crash risk to firms' information environment and found supporting empirical evidence. (e.g., Hutton et al., 2009; Jin and Myers, 2006; Kim and Zhang, 2016; and Kothari et al., 2009). Specifically, based on agency theory and the issue of information asymmetry, several studies in the financial economics literature focus on the managerial incentive to withhold bad news. However, as noted by Jin and Myers (2006), managers can only withhold bad news to a certain time and the sudden release of the news results in a significant downward stock price adjustment.

The extant environmental economic literature examining share price revisions surrounding firm-specific environmental news has documented negative share price adjustments and increased stock price volatility on the release of pollution information under an environmental regulation or environmental crises affecting firms operating within the same industry (e.g., Bowen et al., 1983; Chapple et al., 2013; Griffin et al., 2013; Hamilton, 1995; Heflin and Wallace, 2017; and Klassen and McLaughlin, 1996). A common thread of this literature underlies the valuation role of pollution information as firm-specific value-relevant information to estimate the increased risk of regulatory costs. In addition, several studies found firms can mitigate share price decline by providing more disclosures at the firm-level (e.g., Bowen et al., 1983; Clarkson et al., 2013; and Heflin and Wallace, 2017).

Two competing views exist on the implications of environmental performance for transparency in the corporate information environment. One school of thought contends that socially and environmentally responsible (CSR) firms are also committed to a high ethical standard of transparent practices in financial reporting and therefore are more likely to provide timely disclosures with high information quality (e.g., Bozzolan et al., 2015; Gelb and Strawser, 2001; and Kim et al., 2012). Their empirical evidence indicates that CSR-oriented firms constrain earnings management both through reduced accruals and less detectable real earnings management and tend to provide more financial information.

In contrast, from an agency perspective, another school of thought raises concerns about managerial entrenchment in opportunistically resorting to CSR investments to disguise bad news and detract the attention of shareholders and stakeholder activists from corporate misconduct (Petrovits, 2006; Prior et al., 2008). Supporting this view, they find that firms engaging in more CSR activities provide less transparent and reliable financial information[7]. Hence, whether the incremental information from firms' carbon performance mitigates or contributes to stock price crash risk remains an open empirical question. If high carbon intensity reduces the firm-specific information impounded in share prices, then firms with a higher emission profile are expected to encounter higher crash risk when the information is eventually released to the market.

Specifically, the following regression model is employed to test the two opposing views:

$$\begin{aligned}\text{CrashRisk}_{i,t} = {} & \alpha + \beta_1 \times \text{CARBON}_{i,t} + \beta_2 \times \text{CO2SURPLUS}_{i,t} \\ & + \beta_3 \times (\text{CARBON}_{i,t} \times \text{CO2SURPLUS}_{i,t}) + \textstyle\sum_{j=1}^{N} \gamma_j \times \text{Controls}_{i,t}^{j} \\ & + \textstyle\sum_{k=1}^{M} \delta_k \times \text{CountryIndicator}_{i,t}^{k} + \textstyle\sum_{p=1}^{T} \theta_p \times \text{IndustryIndicator}_{i,t}^{p} \\ & + \textstyle\sum_{q=1}^{9} \vartheta_q \times \text{YearIndicator}_{i,t}^{q} + \varepsilon_{i,t}\ . \end{aligned} \quad (5)$$

Following previous studies (e.g., Chen et al., 2001; and Kim et al., 2014), crash risk (NCSKEWIND/NCSKEWMKT) is measured as the negative conditional skewness of firm-specific weekly returns over the fiscal year. NCSKEWIND and NCSKEWMKT are based on weekly idiosyncratic returns estimated as the natural logarithm of one plus the residual returns from Eq. (1) and a market model excluding contemporaneous and lagged industry returns in Eq. (1), respectively. Similarly, the inverse of the third moment by adding a negative sign was used so that a higher value of NCSKEW/ NCSKEWIND indicates higher crash risk.

Carbon related variables are as defined previously. Several control variables identified as predictors of stock price crash risk in previous studies are also included, namely,

[7] Anecdotally, the recent Volkswagen scandal highlighted the potential impact of corporate misconduct on stock prices when irregularities in emission testing resulted in the company's stock price crashing by 30% and the retraction of several environmental performance awards.

firm size, financial leverage, market-to-book ratio, systematic volatility as previously defined and stock return volatility, calculated as the standard deviation of weekly returns over the current fiscal year (e.g., Boubaker et al., 2014; and Kim et al., 2014).

As shown in Table 5.8, the coefficients of the carbon-related variables are insignificant in all tests, indicating, on average, higher emission propensity does not contribute to or mitigate stock price crash risk measured by both NCSKEWMKT and NCSKEWIND. Though the results do not help to distinguish between the opposing transparent reporting and opportunistic views, they are not unexpected given the mixed findings in the literature. This may in effect reflect that emission performance is less indicative of discretionary disclosures. This interpretation is supported by Kim et al. (2014) who examine the relationship between corporate social responsibility and stock price crash risk. Based on a sample of US firms, after disaggregating the social performance measure, they observe that the individual category of CSR performance, controlling for industry fixed effects, does not predict much firm-specific stock price crash risk, with only very limited evidence for an environmental score on one of the crash risk measures.

Consistent with observations in prior studies, firms that are larger or have lower financial leverage or higher return volatility are, on average, associated with higher stock price crash risks indicated by more skewness in their stock returns (e.g., Boubaker et al., 2014; Damodaran, 1987; and Harvey and Siddique, 2000).

Table 5.8. Regression results for stock price crash risks

	NCSKEWEIND		NCSKEWEMKT	
Independent variable	Est. (1)	Est. (2)	Est. (3)	Est. (4)
CO2	-0.004		-0.072	
	(0.972)		(0.491)	
CO2PRO		0.008		0.002
		(0.325)		(0.853)
CO2SURPLUS	0.008	-0.070	0.010	-0.047
	(0.806)	(0.194)	(0.775)	(0.413)
CO2 X CO2SURPLUS	-0.223		-0.156	
	(0.112)		(0.289)	
CO2PRO X CO2SURPLUS		-0.013		-0.010
		(0.167)		(0.299)
SIZE	0.028^{***}	0.030^{***}	0.033^{***}	0.033^{***}
	(0.000)	(0.000)	(0.002)	(0.003)
RETVOL	5.435^{***}	5.466^{***}	6.936^{**}	6.960^{**}
	(0.000)	(0.000)	(0.010)	(0.010)
LEV	-0.123^{***}	-0.120^{***}	-0.150^{***}	-0.149^{***}
	(0.003)	(0.003)	(0.009)	(0.009)
MB	-0.019	-0.017	-0.006	-0.002
	(0.229)	(0.301)	(0.737)	(0.907)
LNSYSVOL	-0.033^{***}	-0.034^{***}	-0.041^{*}	-0.041^{*}
	(0.002)	(0.001)	(0.074)	(0.071)
Intercept	-0.485^{***}	-0.521^{***}	-0.502^{*}	-0.546^{**}
	(0.005)	(0.003)	(0.061)	(0.037)
Adj R-sqr	0.0662	0.0651	0.0683	0.0651
Prob > F	(<0.001)	(<0.001)	(<0.001)	(<0.001)

Notes: This table presents regression results for stock price crash risks for a sample of 3645 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, NCSKEWEIND and NCSKEWEMKT, is defined as the negative skewness of firm-specific weekly returns over the fiscal year, where firm-specific return is measured as the log of one plus the residual obtained from Eq. (1) and a market model excluding contemporaneous and lagged industry returns in Eq. (1), respectively. CO2 represents the carbon intensity measured as the verified emissions of a firm scaled by sales revenue (tonnes/$000), where verified emissions is the aggregated annual emissions at the listed controlling-entity level based on facility-level emission data verified and reported in the European Union Transaction Log. CO2PRO is an industry-year decile rank of the firm's CO2. CO2SURPLUS is a dummy variable equal to one if the firm has surplus carbon allowances greater than emissions. SIZE is the log of market capitalisation of the firm measured at the end of fiscal year. RETVOL is calculated as the standard deviation of weekly returns over the current fiscal year. LEV is the financial leverage measured as ratio of the book value of total liabilities to total assets at the beginning of the year. MB is the natural log of the ratio of the market value of equity to the book value of equity, measured at the end of fiscal year. LNNIND is the log of the average number of firms in each industry by 2-digit SIC code used to calculate the weekly industry index in Eq. (1). DIVERS denotes a dummy variable equal to one if the firm operates more than one geographic segments (GEOSEG) as reported in the European Union Transaction Log. LNSYSVOL is the log of a firm's systematic volatility measured by the variance of the difference between stock return variance and the variance of the error term ($\varepsilon_{i,t}$) from Eq. (1). All results are from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in all models; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels (two-tailed), respectively.

So far, this study has provided evidence on the impact of corporate carbon performance on firm-specific information. The next section reports results from a series of sensitivity analyses conducted to test the consistency of the results.

5.7 Robustness Checks

In this subsection, additional tests are conducted to check for the robustness of the results to issues related to endogeneity, the selection of the sampling period and industry representation, and the use of alternative models in obtaining proxies for firm-specific information. In summary, these analyses reveal that the results and conclusions are not sensitive to modifications of the research design in relation to the robustness checks.

The first test is performed to address the endogeneity issue. One potential concern is reverse causality. Instead of corporate carbon performance leading to more firm-specific information, it is possible that the level of firm-specific information captured in stock returns causes better carbon performance. Despite a common concern about this potential issue, the reverse causality is unlikely to affect the results in this study as the notion that higher firm-specific information can lead to a reduction in firms' emission propensity is not intuitive. In particular, initiatives in carbon reduction represent long term commitments to carbon management requiring superior management capabilities and are thus less likely to be reversible in the short term. Nevertheless, to address the potential endogeneity issue, stock return synchronicity is regressed on lagged CO2 and CO2PRO instead of the contemporaneous carbon metrics.

Results presented in Estimations (1) and (2), Table 5.9 are qualitatively similar to the primary results reported in Estimations (3) and (6) of Table 5.3. As the reverse causality is unlikely to explain the results, it is less likely that contemporaneous firm-specific information would reduce lagged emission information.

The second set of tests excludes 2008 and 2012 to avoid the potential concern of undue bias that may arise from extreme shifts in price during the global financial crisis and Eurozone crisis. The results, using the more stringent sample, are reported in Estimations (3) and (4), Table 5.9 and the conclusions remain unchanged.

In the third set of tests, firm-years operating in financials and utilities are excluded because of different industry-specific requirements as discussed in Section 5.3. The results reported in Estimations (5) and (6), Table 5.9 are qualitatively unaltered.

Lastly, sensitivity analyses were performed to address the concern that the results may be unduly influenced by the choice of the model used in obtaining the stock return synchronicity measure. More specifically, first, the regressions are replicated using the synchronicity measure based on a market model excluding contemporaneous and lagged industry returns in Eq. (1), which has been widely used in early studies (e.g., Roll, 1988). Estimations (7) and (8), Table 5.9 show results consistent with the primary analyses.

Table 5.9. Robustness checks

Independent variable	Lagged carbon variable		Excluding 2008 and 2012		Excluding Financials and Utilities sectors		Use of alternative proxies SYNCHMKT		LNR2DIFF	
	Est. (1)	Est. (2)	Est. (3)	Est. (4)	Est. (5)	Est. (6)	Est. (7)	Est. (8)	Est. (9)	Est. (10)
CO2	0.364***		0.276***		0.307***		0.173***		0.464***	
	(<0.001)		(0.000)		(<0.001)		(0.008)		(<0.001)	
CO2PRO		0.024***		0.022***		0.027***		0.018***		0.023***
		(<0.001)		(0.000)		(<0.001)		(<0.001)		(0.007)
SIZE	0.194***	0.203***	0.190***	0.199***	0.185***	0.199***	0.169***	0.179***	0.126***	0.132***
	(<0.001)	(<0.001)	(0.000)	(0.000)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
ROAVOL	-1.754***	-1.773***	-0.927**	-0.908**	-0.990***	-0.971***	-1.775***	-1.761***	1.372***	1.399***
	(<0.001)	(<0.001)	(0.023)	(0.030)	(0.005)	(0.007)	(<0.001)	(<0.001)	(0.002)	(0.002)
LEV	-0.261***	-0.255***	-0.094	-0.087	-0.089	-0.074	-0.108***	-0.102	-0.027	-0.022
	(<0.001)	(<0.001)	(0.247)	(0.269)	(0.231)	(0.283)	(0.002)	(0.280)	(0.668)	(0.723)
MB	-0.029*	-0.043**	-0.037*	-0.047**	-0.024	-0.034*	-0.016	-0.023	-0.020	-0.032
	(0.058)	(0.024)	(0.075)	(0.026)	(0.214)	(0.086)	(0.276)	(0.257)	(0.498)	(0.294)
LNNIND	-0.205**	-0.178*	-0.453***	-0.418***	-0.415***	-0.363***	0.543	0.547	-1.123***	-1.111***
	(0.043)	(0.089)	(0.000)	(0.000)	(<0.001)	(<0.001)	(0.159)	(0.141)	(<0.001)	(<0.001)
DIVERS	0.021	0.013	0.028	0.016	0.061**	0.041	0.059**	0.042*	-0.169***	-0.170***
	(0.409)	(0.611)	(0.266)	(0.537)	(0.011)	(0.101)	(0.019)	(0.087)	(0.001)	(0.001)
LNSYSVOL	0.487***	0.486***	0.474***	0.473***	0.472***	0.469***	0.623***	0.621***	-0.009	-0.010
	(<0.001)	(<0.001)	(0.000)	(0.000)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(0.569)	(0.555)
Intercept	-2.369***	-2.412***	-1.656***	-1.763***	-1.681***	-1.902***	-6.225***	-6.290***	-0.470	-0.383
	(<0.001)	(<0.001)	(0.002)	(0.001)	(0.001)	(<0.001)	(<0.001)	(<0.001)	(0.648)	(0.710)

N	3056	3056	2920	2920	3288	3288	3645	3645	3645	3645
R-sqr	0.7231	0.7233	0.6960	0.6967	0.7101	0.7119	0.7605	0.7612	0.0954	0.0942
Prob > F	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)

Notes: This table reports regression results of robustness analyses for a sample of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, SYNCH, is defined as a log transformation of R-Square statistic [$\log\left(R^2/\left(1-R^2\right)\right)$] obtained from estimating Eq. (1). Results in the first two estimations are from regressions of stock return synchronicity on lagged carbon variables. Estimations (3)-(4) and (5)-(6) exclude years 2008 and 2012, and financials and utilities sectors, respectively. Estimations (7) and (8) employs an alternative proxy of stock return synchronicity, SYNCHMKT, a log transformation of R-Square statistic obtained from a market model excluding contemporaneous and lagged industry returns in Eq. (1) as the dependent variable. Estimations (9) and (10) use the difference between the R-square statistics from Eq. (1) and the market model. CO2 represents the carbon intensity measured as the verified emissions of a firm scaled by sales revenue (tonnes/$000), where verified emissions is the aggregated annual emissions at the listed controlling-entity level based on facility-level emission data verified and reported in the European Union Transaction Log. CO2PRO is an industry-year decile rank of the firm’s CO2. SIZE is the log of market capitalisation of the firm measured at the end of fiscal year. ROAVOL is calculated as the standard deviation of the firm’s ROA in the past three years including the current fiscal year where ROA is the net income before extraordinary items scaled by the average total assets. LEV is the financial leverage measured as ratio of the book value of total liabilities to total assets at the beginning of the year. MB is the natural log of the ratio of the market value of equity to the book value of equity, measured at the end of fiscal year. LNNIND is the log of the average number of firms in each industry by 2-digit SIC code used to calculate the weekly industry index in Eq. (1). DIVERS denotes a dummy variable equal to one if the firm operates more than one geographic segments (GEOSEG) as reported in the European Union Transaction Log. LNSYSVOL is the log of a firm’s systematic volatility measured by the variance of the difference between stock return variance and the variance of the error term ($\varepsilon_{i,t}$) from Eq. (1). All results are from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in regression specification except Estimations (3) and (4); all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels (two-tailed), respectively.

Second, the difference between the R-square statistics obtained from Eq. (1) and the market model is used as the dependent variable in Estimations (9) and (10). This measure represents the power of industry-level returns in explaining firm-level return variation over and above the market returns, following Grewal et al. (2017) and Piotroski and Roulstone (2004). A higher difference thus indicates that more industry-level information is reflected in a firm's share price. Further supporting the primary inferences, a positive and significant coefficient on CO2 (CO2PRO) in Estimation (9) [Estimation (10)] of Table 5.9 suggests firms exhibiting high emission intensity (carbon risk profile) tend to co-move more with industry returns, implying there is intra-industry transfer of information to stock prices of firms with a high relative carbon profile.

5.8 Summary

The primary objective of this study is to expand the value-relevance literature on environmental performance information by investigating the impact of carbon performance information on firm-specific information. Existing research on the financial implications of carbon information has predominantly focused on valuation relevance; this study focuses on a potentially important but hitherto unexplored valuation role for carbon performance information in impounding more firm-specific information in share prices relative to industry- and market-wide information. Moreover, studies in this area have not examined the effect of carbon performance on both systematic volatility and idiosyncratic volatility. As such, this study provides insights into how carbon performance improves firms' environment in an attempt to establish the effect on the two individual variation components captured in stock returns.

From the perspective of stakeholder theory and the framework of the resource-based view of the firm, corporate carbon performance represents firm-specific competitiveness and therefore is expected to reveal itself in the firm-specific component of stock returns. Using a standardised stock return synchronicity measure to operationalise the measure of the relative distribution of firm-specific information in stock returns, the empirical results for the test of the impact of carbon performance information on firms' information environment provide strong support for the hypothesis. As expected, stock return synchronicity is positively related to firms' carbon emission profile after controlling for a set of market-, industry- and firm-level attributes. The significant relationship suggests that firms' carbon performance information plays a significant role in impounding firm-specific information into stock prices. In addition, this chapter provides further supportive evidence from systematic volatility and idiosyncratic volatility. Consistent with the hypothesised relationship between carbon performance and firm-specific information, a higher emission profile increases the systematic variation component and reduces the idiosyncratic variation component after controlling for market-, industry-, and firm-level characteristics. Collectively, the results from this study support the hypothesis and are robust to the use of lagged carbon variables, different regression specifications and alternative proxies of key variables. This evidence confirms the importance of corporate carbon performance in explaining the behaviour of stock returns and thus contributes to a better understanding of the role of corporate carbon management in a carbon-constrained economy.

Overall, this study contributes to the literature by providing empirical evidence on the impact of corporate carbon performance on firms' information environment through an increase in firm-specific information impounded in share prices. One implication is a potential role for firms' non-financial performance in explaining variations in the R squared statistic across firms and over time through its effect on stock return synchronicity. Another implication is that the impact on the information environment may affect firms' cost of external finance. The next chapter further investigates the relationship between firms' carbon performance and the cost of equity.

CHAPTER 6

THE EFFECT OF CARBON PERFORMANCE ON THE COST OF EQUITY

6.1 Introduction

6.1.1 Background

The objective of this chapter is to empirically investigate the market perception of corporate carbon riskiness for firms regulated under the European Union Emission Trading Scheme (EU_ETS). Specifically, this study examines whether capital market participants incorporate firms' exposure to carbon risks in their investment decisions through the ex-ante imputed cost of equity.

There is an expanding stream of academic literature on the influence of a broader business theme between corporate social responsibility (CSR) and environmental risk management on firms' financing costs (e.g., El Ghoul et al., 2011; and Sharfman and Fernando, 2008). The reasoning is that firms can benefit from a lower cost of equity finance either through investor preferences or a reduction in the perceived riskiness of future cash flows (Heinkel et al., 2001; Hong and Kacperczyk, 2009). While the existing literature predominantly reports an inverse relationship between the cost of equity and the metrics of CSR or environmental management, the findings are not uniform. The equivocal empirical results are potentially attributed to methodological concerns (Xiao et al., 2013) discussed in the research design (Section 6.2).

Emerging as a subset of environmental risks, climate change related issues have attracted high media attention. Corporate responses to climate change have evolved significantly in the past few decades. Previous debate on whether a firm should improve its environmental performance was primarily around the cost and benefit of investment in reducing pollution (Jung et al., forthcoming). While firms now need to internalise emission costs as a consequence of carbon pricing and emission regulations across jurisdictions (Clarkson et al., 2015), corporate managers are now more interested in whether or how firms can benefit from reducing GHG emissions (IRRC Institute and Trucost, 2009). Moreover, the industry survey commissioned by a coalition of investors, institutions and environmental groups provides evidence of mangers' views that firms' capacity to adapt to a global economy represents strategic opportunities (Cogan, 2006). The recent initiation of several indices tracking only carbon efficient firms also signalled capital market rewards to firms exhibiting leadership in carbon risk management (Aulisi and Schuster, 2016; ET index research, 2016) coupled with anecdotal evidence indicating regressive firms may be perceived as having more risks (IRRC Institute and Trucost, 2009).

In light of the increased attention to the recent high profile issue of risks related to climate change, several studies have documented market assessments of latent carbon liabilities using firms' historical emission information (Clarkson et al., 2015; Griffin et al., 2017; Matsumura et al., 2014). While these studies provided empirical evidence that corporate investment in the reduction in carbon emissions are value-enhancing, they do not establish how corporate carbon management affects firm value. Emerging literature attempting to link corporate carbon management with improved financial performance through enhanced resource utilisation has provided evidence of better operational efficiency because of effective carbon management (e.g., Sinkin et al., 2008; and Tang and Luo, 2014). These studies provide several explanations that firms may enhance their firm value by improving carbon management contributing to better financial performance. Nonetheless, few studies[8] provide direct evidence as to whether

[8] A notable example is Chen and Gao (2012), discussed in Section 3.1.3 of Chapter 3.

and/or how a firm's emission profile influences investors' perceptions of riskiness in their assessment of firm value – a capital market response that is under-investigated in existing literature. Prior studies have examined the broader question of whether better carbon performance enhances firm value. In contrast, this study seeks to advance the understanding of the effects on firm value by investigating an external influence, namely, whether a firm's efforts in reducing carbon emissions also alter investors' perception of the firm's risk exposure as revealed by the ex-ante implied cost of equity.

6.1.2 Development of hypotheses

Theoretical developments in the risk management literature suggest a number of explanations for the influence of carbon exposure on the cost of equity, including both lowered systematic risk and lower idiosyncratic risk through improved legitimacy, economic resilience, investor preference and less information asymmetry. Each is discussed, in turn, below.

First, according to institutional theory, firms can gain legitimacy through reductions in emissions due to heightened social norms as discussed in detail in Section 3.2. Consequently, increased support from investors may contribute to a lower cost of equity. In addition, carbon-intensive firms may remain vulnerable to future adverse regulatory, physical and corporate influences such as increased costs of compliance with more stringent policies, reputational damage from impaired brand image, substantial litigation risk or exposure to future explicit claims resulting in a decrease in market value.

Second, reduced exposure to carbon constraints may improve a firm's resilience to economic shifts in a carbon-constrained economy. Thus, the reduced variability in performance driven by a firm's exposure to systematic risks may lower the cost of equity.

Third and similar to the institutional influence argument, Heinkel et al. (2001) presents a theoretical model based on investor preferences, illustrating that exclusionary investing by green investors will lead to high-emitting firms being limited to a smaller non-green investor base. The limited diversification and liquidity risks from a smaller investor base thus lead investors in non-green stocks to demand a higher required rate of return in compensation. In support of this view, Hong and Kacperczyk (2009) provide empirical evidence of higher expected returns of "sin" stocks than comparable stocks. They attribute the higher cost of equity to the negative screening strategies imposed by norm-constrained investors, resulting in the inclusion of fewer 'sin' stocks in their portfolio relative to neutral investors.

Fourth, a lower of cost of equity may result from the reduced information asymmetry of firms' exposure to future carbon constraints. According to the capital market equilibrium model developed by Merton (1987), allowing for incomplete information, the cost of equity is higher for high-emitting firms because of a smaller investor base with less information available. To illustrate, low-emitting firms may obtain more publicity from the collection and disclosure of information through media and analysts' coverage (Bansal, 2005). Further, information about corporate carbon emissions may provide incremental information to investors to infer a firm's commitment to reducing carbon emissions (Clarkson et al., 2013). Thus the reduced information asymmetry in assessing a firms' long-term carbon performance may reduce the cost of equity.

Accordingly, building on these theoretical arguments based on the reduced information asymmetry and uncertainties in future cash flows, this study proposes a testable hypothesis as follows: *ceteris paribus*, firms exhibiting high carbon risks have higher cost of equity than firms exhibiting low carbon risks.

6.1.3 Research overview

The implied cost of equity based on earnings forecasts and share prices has been adopted to empirically estimate the ex-ante cost of equity of a firm in both accounting and finance literature (e.g., Dhaliwal et al., 2011; El Ghoul et al., 2011; Francis et al., 2005; Hail and Leuz, 2006; and Hribar and Jenkins, 2004). Specifically, employing a sample of firms operating across multiple industries regulated under the EU_ETS from 2006 to 2015, this chapter first explores the effect of a firm’s carbon emission profile on the implied cost of equity, reflecting the market perception of firms’ carbon risk. Second, the sample firms are partitioned into high- versus low-emitting subgroups. In sum, this study finds that the overall carbon intensity neither increases nor decreases the carbon risk assessed by investors. However, carbon emissions by high-emitting firms are associated with higher investor perception of the firm’s riskiness, manifesting in a higher cost of equity.

Evidence of the market pricing of carbon risk is important to both academics and practitioners. There is a growing demand for understanding the financial consequences of the risk of carbon constraints in the light of regulatory initiatives towards a low carbon economy regionally and internationally. Few empirical studies have investigated the carbon risk assessed by capital market participants. Accordingly, this study addresses the shortfall in the literature by providing insights into investors’ assessment of firms' carbon risk from their historical emission profile as revealed by the cost of equity financing. Other empirical studies investigating the broader notion of environmental risks/CSR often rely on scores rated by third parties, such as Kinder, Lydenberg, Domini and Co. (KLD) and Innovest, to measure various aspects of firms' environmental performance/CSR (e.g., Goss and Roberts, 2011; and Sharfman and Fernando, 2008), these ratings are not directly used by regulators or available internally within a firm in allocating resources. Thus, this study provides direct evidence on the market pricing of carbon risk – a risk factor under increasing regulatory scrutiny.

In addition, previous research in market pricing of environmental risks is limited in scope in terms of industry coverage. Some previous studies are confined to a particular industry (e.g., Griffin and Mahon, 1997) but there may be divergence in societal interests and environmental priorities across industries (Holmes, 1977; Ingram, 1978). However, as outlined in the regulatory background in Chapter 2, with the increasing scope of GHG coverage under carbon regimes across various business sectors, carbon risk is a common risk factor applicable to multiple industries. Using a multi-industry design, this study provides further evidence on the effect of relative carbon risk exposure on the cost of equity using an intra-industry rank of carbon intensity. While emerging empirical evidence has attached carbon management to improved operating performance, this study provides evidence that a firm's leadership relative to industry peers in managing carbon impacts reduces the market's perception of firm riskiness, manifested in the cost of equity.

This study also provides evidence that over-compliance, as indicated by a surplus of allowances under the EU_ETS, can mitigate the effect of a high carbon risk profile on assessed carbon risk. Further, this study considers the role of benchmarking emission information across firms within an industry in informing capital market participants about firms' carbon risk. Thus, this study provides additional insights into the comparability of emission information.

Finally, adjusting for the predicted forecast errors in analysts' earnings forecasts used in estimating the cost of equity measure, this study finds consistent evidence that the relative carbon risk profile has a significant positive impact on the cost of equity. Overall, this chapter produces consistent evidence indicating that firms exhibiting leadership in managing carbon impacts are rewarded with a lower cost of equity than their industry peers.

The remainder of the chapter is organised as follows. The next section discusses the choice of research design and empirical constructs followed by the section describing the sample and data used in this study. The univariate results are then reported, followed by the results of the multivariate regression analyses. In addition, further analyses are conducted and presented following the primary results. A series of sensitivity analyses are conducted and summarised in the section on robustness checks. The last section summarises this chapter.

6.2 Construction of Variables and Empirical Design

The section describes the measurement of empirical constructs used as the dependent variable and other explanatory and control variables identified from prior studies and included in the econometric modelling.

6.2.1 Measurement of the cost of equity

Following the method advocated and widely used by numerous researchers in accounting and finance (e.g., Dhaliwal et al., 2011; Francis et al., 2005; Hail and Leuz, 2006; Hribar and Jenkins, 2004, and Naiker et al., 2013) this study measures the firm level cost of equity by estimating the ex-ante cost of equity implied in stock prices and analyst forecasts of earnings.

As the cost of equity is not directly observable, two general approaches have been employed in empirical studies to develop proxies for the cost of equity to a firm. One approach relies on average realised returns based on capital asset pricing models (e.g., Core et al. 2008; Jones and Frost 2017; Khan 2008; and Renneboog et al. 2008); the other approach estimates an ex-ante imputed cost of equity using earnings forecasts.

Based on the assumption that information surprises are zero in expectation through time, an average of ex-post realised returns from conventional asset pricing models can serve as an estimate of the cost of equity. Despite being a standard methodology in finance, cost of equity estimates deduced from average realised returns are criticised for potential imprecision because realised returns are extremely noisy at the firm level (Strong and Xu, 1997). In particular, it has been suggested that returns derived from a single-factor market model or an augmented three-factor model deliver unreliable estimates of the cost of equity thus the call for further research to develop alternative proxies (Elton, 1999).

In contrast to the use of realised returns, an ex-ante implied cost of equity is obtained using numerical techniques to find the discount rate that equates the current stock price with the future cash flows based on analysts' earnings forecasts (e.g., Gebhardt et al., 2001). The discount rate represents the investors' expected return based on their perception, in aggregate, of firm riskiness and therefore proxies for the cost of equity. The use of accounting-based input variables (i.e., analysts' earnings forecasts) in the estimation of the cost of equity provides a methodological advantage by explicitly controlling for variation in growth and cash flows. In addition, this approach does not require a long window of historical returns to calculate an average realised return and therefore allows estimates to reveal more recent changes in a firm's riskiness. Pástor et al., (2008) provide further evidence on the usefulness of the implied cost of equity approach compared with realised returns in capturing the time-series variation in expected returns, which is another desirable characteristic of a good proxy for the cost of equity. Accordingly, this study adopts an accounting-based approach to estimate the implied cost of equity.

Existing literature suggests several methods, which differ in their assumptions of terminal values, to compute the ex-ante implied cost of equity. In evaluating the construct validity, Botosan and Plumlee (2005) and Botosan et al. (2011) assess alternative measures based on the relationship between the individual proxy and known risk characteristics at firm level, concluding that the target price model and the price-earnings-growth ratio model yield reliable estimates. To alleviate the bias from the use of an individual model, some researchers employ an average of the implied cost of equity obtained from different models. However, the validity of this approach in providing a consistently accurate measure is not supported by Botosan et al. (2011).

As described in the data source below, earnings forecast information is obtained from the Institutional Brokers' Estimate System (I/B/E/S). Target price forecasts and long-term earnings forecasts are not generally available for sample observations in this study. Hence, to alleviate the potential limit of conclusiveness of analyses because of sample restrictions by imposing further data constraints, this study employs a modified PEG model implemented by Easton (2004) to estimate the implied cost of equity ($ICEC_{MPEG}$) as the primary measure for the cost of equity of a firm. The modified PEG model is the best measure among the remaining proxies evaluated by Botosan et al. (2011). In practice, this parsimonious model is also pervasively adopted by consulting institutions for stock selection and recommendations (Easton, 2004; El Ghoul et al., 2011). To check for consistency, this study also constructs a commonly used alternative measure of the implied cost of equity following the residual-income valuation model developed by Gebhardt et al. (2001), which outperforms other models in Guay et al. (2011)'s survey of implied cost of equity measures.

Specifically, this study imputes the implied cost of equity in accordance with Easton (2004) by solving for the internal rate of return $ICEC_{MPEG}$ specified as the following:

$$P_{i,t}=\frac{FEPS_{i,t+2}+ICEC_{MPEG_{i,t}}\times DPS_{i,t+1}-FEPS_{i,t+1}}{ICEC_{MPEG_{i,t}}{}^{2}}, \tag{6}$$

where $P_{i,t}$ is the share price for firm i at time t; $DPS_{i,t+1} = DPOUT_{i,t} \times FEPS_{i,t+1}$ is the firm's forecasted dividends per share in time t+1, where $DPOUT_{i,t}$ is the actual dividend payout ratio calculated as the dividends per share divided by the actual earnings per share in time t; $FEPS_{i,t+1}$ is the one-year-ahead earnings per share forecasted by analysts reported in I/B/E/S; and $FEPS_{i,t+2}$ is the two-year-ahead earnings per share forecasted by analysts reported in I/B/E/S. Thus $ICEC_{MPEG}$ is the imputed cost of equity derived from the modified price-earnings-growth ratio bounded by 0% and 100%.

6.2.2 Construction of test variables and control variables

This chapter uses the same definitions of carbon variables as in Chapter 5, consistent with prior literature, in capturing firms' risk exposure to carbon constraints. Following previous studies (e.g., Chen and Gao, 2012 and Clarkson et al., 2013;), an absolute measure of carbon emission profile (CO2) is measured as the carbon intensity ratio using the verified emissions of a firm scaled by sales revenue ($000), where verified emissions are the aggregated annual emissions at the listed controlling-entity level from facility-level emission data verified and reported by the EUTL at the end of April following each compliance year.

To further investigate the impact of a firm's carbon risk exposure relative to its industry peers, CO2 is then transformed to an intra-industry decile rank on an annual basis to measure the relative carbon performance of the firm (CO2PRO), similar to the methods employed in prior studies (e.g., Clarkson et al., 2011; and Clarkson et al., 2015).

CO2SURPLUS is an indicator variable that takes the value of one if a firm has carbon allowances greater than carbon emissions and zero otherwise. It proxies for over-compliance in the regulatory context.

Firm-specific risks, commonly identified in previous literature as cross-sectional determinants of ex-ante firm-level cost of equity, are included as control variables in the multivariate regression model. Specifically, these include: market beta; size; and the book-to-price ratio. Each of these control variables is discussed, in turn, below.

Market beta (BETA): Market beta is a measure of the level of systematic risk of a firm. According to the capital asset pricing model used to determine an appropriate theoretical required rate of return of an asset, a higher market beta results in a higher expected return by investors in compensation for their exposure to undiversifiable risks (e.g., Fama and French, 1992; Lintner, 1965; and Sharpe, 1964). BETA is the slope coefficient from the regressions of a firm's excess returns on the monthly value-weighted market index excess returns over a rolling 60-month window ending in the current fiscal year. A minimum of 18 monthly returns is required during the 60-month window interval to calculate BETA. The sign on BETA is predicted to be positive in the econometric model.

Firm size (SIZE): SIZE is measured as the natural logarithm of the market value of equity of a firm. Using firm size as a proxy for the firm's information environment, previous studies found larger firms exhibit less information asymmetry because of a high level of publicity resulting in a lower cost of equity (e.g., Bowen et al., 2008; Dhaliwal et al., 2011; El Ghoul et al., 2011; and Gebhardt et al., 2001). Thus, a negative association between firm size and the cost of equity is expected because more information is likely to be available for larger firms.

Book-to-price ratio (BTP): The book-to-price ratio is positively associated with ex-post realised returns as documented in the asset pricing literature (Fama and French, 1992). In addition, prior literature employing an ex-ante implied cost of equity found the book-to-price ratio to be a positive determinant (e.g., Clarkson et al., 2013; Gebhardt et al., 2001; and Hail and Leuz, 2006). BTP is calculated as the ratio of the book value to market value of equity. Based on prior findings, BTP is predicted to be positively correlated with the cost of equity.

Hence, to address the research question whether a firm's carbon risk influences the investors' perception of firm riskiness, the following model is employed:

$$\begin{aligned} \text{ICEC}_{\text{MPEG}\,i,t} = {} & \alpha + \beta \times \text{CARBON}_{i,t} + \gamma_1 \times \text{BETA}_{i,t} + \gamma_2 \times \text{SIZE}_{i,t} + \gamma_3 \times \text{BTP}_{i,t} \\ & + \textstyle\sum_{k=1}^{M} \delta_k \times \text{CountryIndicator}_{i,t}^{k} + \sum_{p=1}^{T} \theta_p \times \text{IndustryIndicator}_{i,t}^{p} \\ & + \textstyle\sum_{q=1}^{9} \vartheta_q \times \text{YearIndicator}_{i,t}^{q} + \varepsilon_{i,t}. \end{aligned} \tag{7}$$

Year indicators are included in all regressions in this study to account for any systematic time variation. In addition, because this study involves firms operating in various industry sectors across different member states in Europe, industry and country fixed effects are included to account for potential variability in the cost of equity because of industry membership and other cross-nationally institutional differences not otherwise controlled. Based on the hypothesis, if CARBON captures a firm's carbon risk and thus influences the market's perception of firm riskiness, then β should be positive.

6.3 Sample and Data

To empirically examine the effect of firms' carbon risk on investors' perception of firm riskiness, sample observations for this study consist of publicly listed firms regulated under the EU_ETS, subject to the data availability from other databases including: annual carbon related variables at the listed controlling-entity level, which is the aggregated measure based on facility-level emission data provided in the EUTL as detailed in Chapter 4. Requisite firm financial variables and stock data are obtained from the Datastream database and forecasts of accounting earnings per share provided by analysts are from I/B/E/S. To construct the primary cost of equity measure following Easton (2004), the calculation also requires that analysts' consensus forecasts of two-year-ahead earnings per share ($FEPS_{i,t+2}$) to be greater than the forecasts of one-year-ahead earnings per share ($FEPS_{i,t+1}$). The operation of the EU_ETS restricts the sample period to 2006-2015 and this study employs unbalanced panel data allowing firms to enter and exit the panel to alleviate survivorship bias.

The intersection of databases with sufficient data to construct the requisite measures provides a final sample of 2085 firm-year observations comprising 260 unique firms from 2006 to 2015. The requirement of data availability for earnings forecasts in I/B/E/S to compute the cost of equity measure represents the greatest sample attrition for this study; the industry-year frequency distribution remains similar to that reported in the carbon dataset shown in Table 4.2. Thus, further data requirements do not appear to affect the relative composition of the sample.

Three main industry sectors dominate the sample observations: 22.1% of the sample firms are from the basic materials sector, 26.3% from the industrials sector and 21.4% from the consumer goods sector. Firm years from these industries in total represent 69.7% of the sample. The telecommunications sector is the least represented with less than 1% of the sample. The number of observations increased steadily over the sample period with a peak in 2013. This is consistent with the larger sample distribution reported in Table 4.2, reflecting the increased scope of emission coverage by the EU_ETS. For robustness checks, the sample is further limited to companies not operating in the financials sector (by excluding Standard Industrial Classification (SIC) Code=8000) because of heavy regulations and different accounting rules, thus making their financial figures less comparable to those of other firms. In addition, utilities (SIC Code=7000) firms are excluded because they are subject to different regulatory disclosure requirements.

6.4 Descriptive Statistics and Univariate Results

Table 6.1 reports the descriptive statistics of the key variables for the sample of 2085 firm-year observations used for the primary analyses. The cost of equity estimated based on the Easton (2004) model ($ICEC_{MPEG}$) has a mean (median) of 12.80% (11.1%).

The mean (median) value for the carbon intensity measure (CO2) is 0.0970 (0.0130). This indicates that firms in the final sample, on average, emit 0.0970 tonnes of Scope 1 GHG emissions per $1000 of sales. There is considerable cross-sectional variation in CO2, with the 5th to 95th percentile ranging from 0.0003 to 0.5520 tonnes per $1000 of sales. The next two rows of Table 6.1 provide descriptive statistics for the sample partitioned into firms with a surplus and those with a deficit in their allowance account. The deficit group represents firms with carbon allowances less than their carbon emissions; the surplus group comprises firms with carbon allowances greater than their carbon emissions. The surplus group has a lower mean CO2 of 0.086 compared with 0.122 for the deficit group (significantly different at the 1% level). Consistent with resource-dependence theory, carbon efficient firms are likely to accumulate a surplus allowance account reflecting over-compliance with the acceptable emissions regulated by EU_ETS, which manifests in a competitive advantage to the firm.

Table 6.1. Descriptive statistics

Measures	Mean	Standard Deviation	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile
Implied Cost of Equity Capital							
$ICEC_{MPEG}$	0.128	0.075	0.029	0.086	0.111	0.156	0.254
Carbon Intensity Measure							
CO2	0.097	0.201	0.000	0.003	0.013	0.095	0.552
CO2 (Deficit)	0.122	0.249	0.000	0.002	0.011	0.113	0.661
CO2 (Surplus)	0.086	0.174	0.000	0.003	0.013	0.089	0.436
Firm and Industry Characteristic							
BETA	1.071	0.493	0.338	0.727	1.043	1.363	1.904
SIZE	16.878	2.675	12.888	14.899	16.615	18.476	21.861
BTP	0.656	0.597	0.003	0.298	0.556	0.884	1.674

Notes: This table summarises the key measures used in this study for a sample of 2085 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. $ICEC_{MPEG}$ is the implied cost of equity based on the Easton (2004) modified PEG estimate at the end of the fiscal year. CO2 represents carbon intensity measured as verified emissions scaled by sales revenue (tonnes/$000), where verified emissions are the aggregated annual emissions at the listed controlling-entity level. CO2 (Deficit) indicates the CO2 measure for the subsample of firms with carbon allowances less than carbon emissions and CO2 (Surplus) indicates the CO2 measure for the subsample of firms with carbon allowances greater than carbon emissions. BETA is the slope coefficient from the regressions of a firm's excess returns on the monthly value-weighted market index excess returns over a rolling 60-month window ending in the current fiscal year where a minimum of 18 monthly returns is required during the 60-month window interval to calculate BETA. SIZE is the log of market capitalisation of the firm, measured at the beginning of the fiscal year. BTP the ratio of book value to market price of equity, measured at the beginning of the fiscal year.

As explained in Section 5.4 of Chapter 5, the surplus group in this study is proportionately greater than those reported by Clarkson et al. (2015) for their sample of 2006-2009.

The distribution of market beta (BETA), which measures firms' systematic risk, is similar to that reported in previous studies (e.g., El Ghoul et al., 2011), with a mean (median) of 1.071 (1.043) ranging from 0.727 at the lower quartile to 1.363 at the upper quartile. The mean and median for SIZE, 16.878 and 16.615, respectively, reflect the larger market capitalisation of sample firms in this study compared with the broader initial sample of firms with a mean (median) of 15.242 (15.383) (Table 5.1). This is consistent with the previous finding that I/B/E/S analysts are more likely to follow large firms (Zhang 2006). The mean book-to-price ratio (0.656) indicates that stock prices for sample firms are traded well above their book value.

Panel A, Table 6.2, presents the Pearson pair-wise correlations among the main variables used in the regression analyses. All the explanatory variables display the expected relationships with the dependent variable. Overall, there appears to be no high correlations causing any serious multicollinearity concern between the explanatory variables in the regression, with all the variance inflation factors below two (Hair et al., 1998; Gujarati, 2004). Panel B, Table 6.2, depicts the univariate analysis that compares the mean of cost of equity ($ICEC_{MPEG}$) of firms between the lowest and the highest intra-industry decile of carbon intensity. The mean cost of equity ($ICEC_{MPEG}$) of firms within the top decile of CO2 is 14.6%, compared with 11.8% for firms within the bottom decile. Thus, $ICEC_{MPEG}$ is lower for firms displaying lower intra-industry carbon risk profile; the difference is statistically significant at less than the 1% level

Table 6.2. Correlation matrix and univariate results

Panel A: Pearson correlation matrix

	$ICEC_{MPEG}$	CO2	BETA	SIZE	BTP
$ICEC_{MPEG}$	1				
CO2	0.04^{*}	1			
BETA	0.32^{***}	0.03^{*}	1		
SIZE	-0.31^{***}	-0.07^{***}	-0.06^{***}	1	
BTP	0.44^{***}	0.05^{**}	0.25^{***}	-0.28^{***}	1

Panel B: Univariate results of ICECMPEG between the highest and lowest decile of firms' carbon intensity (CO2)

$ICEC_{MPEG}$	Mean	Standard Deviation	5^{th} Percentile	25^{th} Percentile	Median	75^{th} Percentile	95^{th} Percentile
CO2 (Top Decile)	0.146	0.072	0.043	0.103	0.136	0.170	0.277
CO2 (Bottom Decile)	0.118	0.063	0.019	0.083	0.109	0.154	0.237
Wilcoxon Z test	**3.885*****						
p–value	**(<0.001)**						

Notes: Panel A of this table presents the Pearson correlation matrix among the regression variables for a sample of 2085 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. $ICEC_{MPEG}$ is the implied cost of equity capital based on the Easton (2004) modified PEG estimate at the end of the fiscal year. CO2 represents carbon intensity measured as verified emissions scaled by sales revenue (tonnes/$000), where verified emissions are the aggregated annual emissions at the listed controlling-entity level. BETA is the slope coefficient from the regressions of a firm's excess returns on the monthly value-weighted market index excess returns over a rolling 60-month window ending in the current fiscal year where a minimum of 18 monthly returns is required during the 60-month window interval to calculate BETA. SIZE is the log of market capitalisation of the firm, measured at the beginning of the fiscal year. BTP the ratio of book value to market price of equity, measured at the beginning of the fiscal year. Panel B reports the mean comparison test for $ICEC_{MPEG}$ between the top and bottom decile of firms' CO2 using the Wilcoxon Z test; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels (two-tailed), respectively.

(p< 0.001), using the Wilcoxon Z test of the sample mean differences in $ICEC_{MPEG}$. However, results from the univariate analyses should be interpreted with caution because they do not consider differences in other firm-specific attributes underlying operations. Accordingly, the next section investigates the relationships in conjunction with other firm characteristics identified as affecting firms' cost of equity.

6.5 Empirical Results

Using a multivariate regression design, this section investigates the effect of firms' carbon risk on the market's perception of firm riskiness measured by the ex-ante imputed cost of equity for a sample of firms regulated under the EU_ETS during 2006-2015. This section presents results of the regression analyses designed to test the hypothesis.

Table 6.3 reports the results from regressing the primary cost of equity estimate, $ICEC_{MPEG}$, on CO2 and other explanatory variables using pooled cross-sectional time-series regressions with standard errors adjusted for clustering at the firm level to ensure the robustness of results (Petersen, 2009). The explanatory variables include control variables of BETA, SIZE, and BTP as well as year, industry and country fixed effects. Results for the entire sample of 2085 firm-year observations from Estimation (1) are presented in the first column.

Table 6.3. Regression results for implied cost of equity based on modified price earnings growth model on carbon intensity

Independent variable	Predicted Sign	$ICEC_{MPEG}$				
		Est. (1) Full Sample	Est. (2) High-Emitting	Est. (3) Low-Emitting	Est. (4) Deficit	Est. (5) Surplus
CO2	+	0.008	0.115**	-0.000	0.022	-0.004
		(0.844)	(0.026)	(0.543)	(0.693)	(0.504)
BETA	+	0.034***	0.028***	0.029***	0.031***	0.031***
		(<0.001)	(<0.001)	(0.004)	(<0.001)	(<0.001)
SIZE	–	-0.011***	-0.005***	-0.009***	-0.004***	-0.007***
		(<0.001)	(<0.001)	(<0.001)	(0.003)	(<0.001)
BTP	+	0.036**	0.010***	0.016***	0.011***	0.010***
		(0.040)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
Intercept		0.244***	0.132***	0.206***	0.117***	0.170***
		(<0.001)	(<0.001)	(<0.001)	(0.003)	(<0.001)
Subsample comparison of coefficients on CO2		–	χ^2=5.67 ** (*p*-value = 0.013)		χ^2= 0.17 (*p*-value = 0.677)	
Year, industry and country fixed effect		Included	Included	Included	Included	Included
Adj R-sqr		0.2146	0.2983	0.3210	0.3367	0.2947
Prob > F		(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)

Notes: This table summarises regression results for a sample of 2085 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, $ICEC_{MPEG}$, is the implied cost of equity capital based on the Easton (2004) modified PEG estimate at the end of the fiscal year. The first column presents the regression results based on the full sample. In the second and third columns, the sample was partitioned into two subsamples in accordance with their emission profile: high-emitting firms with carbon intensity greater than the sample mean; and low-emitting firms with carbon intensity less than the sample mean. In the fourth and fifth columns, the sample was separated into two subgroups in accordance with their carbon allowances balances: firms with carbon allowances less than carbon emissions (Deficit) and firms with carbon allowances greater than carbon emissions (Surplus), respectively. The main test variable, CO2, represents carbon intensity measured as verified emissions scaled by sales revenue (tonnes/$000), where verified emissions are the aggregated annual emissions at the listed controlling-entity level. BETA is the slope coefficient from the regressions of a firm's excess returns on the monthly value-weighted market index excess returns over a rolling 60-month window ending in the current fiscal year where a minimum of 18 monthly returns is required during the 60-month window interval to calculate BETA. SIZE is the log of market capitalisation of the firm, measured at the beginning of the fiscal year. BTP the ratio of book value to market price of equity, measured at the beginning of the fiscal year. All results are from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in all regression specifications; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

The second (third) column displays the results from Estimation (2) [Estimation (3)] for sample firms partitioned into a subsample of high- (low-) emitting firms with CO2 greater (less) than the sample mean. The last two columns illustrate results for sample firms separated into two subgroups in accordance with their allowance balances, namely the deficit group of firms with carbon allowances less than carbon emission [Estimation (4)], and the surplus group of firms with carbon allowances greater than carbon emission [Estimation (5)], respectively. In all estimations, coefficients of control variables are uniformly loaded with the predicted sign and significant at conventional levels consistent with prior literature. Thus, the econometric model appears to be relatively well specified, providing additional assurance to the interpretation of results.

The test variable of Estimation (1) for the entire sample is CO2. In contrast to the univariate results, the coefficient estimate for CO2 is positive but insignificant at conventional levels (first column, of Table 6.3). Thus, the analyses are not consistent with the prediction that firms exhibiting high carbon risk have a higher cost of equity than firms exhibiting low carbon risk. The next regressions examine separately the effects on the cost of equity for high- and low-emitting firms.

Prior industry research suggests that the financial implications of carbon emissions vary across firms with those depending on high carbon-intensive operations and supply chains most significantly exposed to carbon risk (Cogan et al., 2008; IRRC Institute and Trucost, 2009; UNEP Finance Initiative, 2006). Further, the increasing adoption of climate-proofing analysis in portfolio investment and the emergence of several emission tracking indices (e.g., Denniss et al., 2014; and ET index research, 2016) indicate an increasing recognition of firms' exposure to carbon-related risks, with high-emitting firms subject to more specific carbon risk assessments by the investor community (e.g., Aulisi and Schuster, 2016).

In contrast, carbon-efficient operations with favourable mitigation effects are more likely to attract capital investment flows especially from eco/green investors. Accordingly, firms' high-emitting profile and exposure to carbon risks in a carbon-constrained future will potentially adversely affect their cost of equity. Underlying this argument is the view that high-emitting firms are more sensitive to carbon risk compared with low-emitting firms because the former may find it difficult to fully pass on carbon costs in an unfolding low-carbon economy (Clarkson et al., 2015; Cogan et al., 2008; IRRC Institute and Trucost, 2009).

A focus on high polluting firms is commonly adopted in the environmental literature to understand the financial implications of environmental regulations (e.g., Clarkson et al., 2008; Clarkson and Richardson, 2004; and Schneider, 2011). Accordingly, to examine the differences in firm riskiness perceived by market investors for firms differing in carbon profile, the full sample is partitioned into high- and low-emitting firms based on the sample mean carbon intensity. The high-emitting group comprises 388 firm-year observations with carbon emissions greater than the sample mean; the low-emitting group comprises 1697 firm-year observations with carbon emissions less than the sample mean. The regression analyses for the high- and low-emitting groups are Estimation (2) and Estimation (3), respectively.

The results of Estimation (2) are presented in the third column, Table 6.3. The coefficient on CO2 for the high-emitting sub-sample is positive and statistically significant at the 5% level. Thus, as predicted, an increase in carbon intensity from high-emitting firms increases the cost of equity, supporting the industry view (IRRC Institute and Trucost, 2009) of the market assessment of firms' carbon risks. This is also consistent with prior studies (e.g., Clarkson et al., 2015) that find the market values carbon emissions negatively for firms that are more susceptible to regulatory requirements, thereby rendering carbon impacts as highly salient issues perceived as risks (Goss and Roberts, 2011). On average, an increase of one standard deviation in CO2 gives rise to a 2.3% increase in $ICEC_{MPEG}$, indicating that a firm's carbon intensity has an economically significant effect on the cost of equity.

In contrast, the coefficient on CO2 in Estimation (3) is negative but not statistically different from zero for the subsample of low-emitting firms as reported in the third column, Table 6.3. This suggests carbon intensity does not appear to affect the cost of equity for low-emitting firms. A possible reason is that carbon costs for these firms are considered immaterial because of an inherently low risk and therefore any improvement in carbon efficiency does not appear to significantly adjust the firm's risk profile (e.g., Goss and Roberts, 2011; Jung et al., forthcoming; and Sharfman and Fernando, 2008).

Finally, a joint seemingly unrelated regression estimation is employed to compare the coefficients of CO2 between the high- and low-emitting subsamples. As reported in Table 6.3, for Estimations (2) and (3), χ^2 has a value of 5.67, which is significant at the 5% level. This indicates that the association between carbon intensity and the cost of equity differs between high- and low-emitting firms with a significant positive association observed for high-emitting firms. Hence, firms with emissions exceeding the average emission profile of the sample are perceived as riskier investments by market participants, resulting in a higher discount rate being applied to the firm's future cash flows; emissions below the average emission profile of sample firms are not priced.

Taken together, while the magnitude of carbon intensity is not relevant in the market pricing for the full sample, it appears that investors condition their assessment of carbon risks on a firm's relative emission profile and assign a higher risk premium to carbon emissions from high-emitting firms. Collectively, these findings are consistent with the theoretical prediction that the relationship is more observable in a context where the pressures for firms to improve their carbon footprint are stronger since carbon risks largely originate from the urgency to comply with a regulatory requirement (Clarkson et al., 2015; Sharfman and Fernando, 2008).

While the magnitude of carbon intensity is not associated with firms' financing costs based on results for the full sample and low-emitting firms, previous literature suggests that proactive environmental strategies of a discretionary nature may result in over-investment in carbon technologies and divert resources to investments that do not benefit shareholders (e.g., Barnea and Rubin, 2010). Accordingly, the analysis is extended to examine the association between carbon intensity and the cost of equity for firms that over- and under-comply with existing regulatory requirements.

Existing literature presents competing views on the valuation implications of firms' over-compliance with environmental regulations. One stream of thought asserts that investments in environmental initiatives beyond the minimum requirement of an environmental regulation are not valued because they represent unnecessary costs to shareholders, potentially involving large initial outlay (Friedman, 1970; Tsoutoura, 2004; Walley and Whitehead, 1994). Another line of argument in recent management literature suggests that over-compliance with a regulation may reduce the sensitivity of cash flows to future regulatory changes, thereby lowering the perceived riskiness to investors (Clarkson and Richardson, 2004; Sharfman and Fernando, 2008).

Of immediate relevance to this research is the market mechanism by which emission allowances are allocated at the firm level that requires firms to surrender emission allowances equivalent to their carbon emissions at the end of the compliance cycle. Firms with a deficit in allocated allowances will need to purchase more allowances from the carbon market whereas firms with a surplus can either bank or sell their excess allowances. The allocation of allowances to firms by each member state should take into consideration the average emission profile of the industrial activity as well as the best available clean technologies to ensure that the allocation process is not unduly biased towards certain undertakings (Clarkson et al., 2015; European Commission, 2004). Hence, firms that are proactive in reducing carbon impacts are more likely to have a surplus of allowances reflecting for their over-compliance with the regulatory requirement of an expected emission level based on industry-average carbon efficiency and available clean technologies.

One concern for firms' investment in emission reduction as suggested in prior studies (Friedman, 1970; Walley and Whitehead, 1994) is that the marginal costs of proactive over-compliance with existing environmental regulations may outweigh the marginal benefits. To provide further insights into the equivocal implications of firms' over-compliance and under-compliance with the allocated emission level, the next set of analyses are of subsamples partitioned in accordance with their emission allowance accounts.

The deficit group comprises 714 firm-year observations with carbon emissions greater than the allocated emission allowances and the surplus group consists of 1371 firm-year observations with carbon emissions less than the allocated emission allowances. The results of Estimation (4) and (5) are presented in the last two columns of Table 6.3

for the deficit and surplus groups, respectively. The test coefficients are statistically significant for BETA, SIZE and BTP loaded with the expected sign at the 5% level or lower. Specifically, the insignificant association between CO2 and $ICEC_{MPEG}$ for both the deficit and surplus groups indicates that over-compliance or under-compliance with existing environmental requirements neither increases nor attenuates the market pricing of CO2. These results are similar to those of the full sample in Estimation (1). Consistently, employing a joint seemingly unrelated regression estimation, the results for the comparison of coefficients on CO2 between the deficit and surplus group is displayed at the bottom of the last two columns of Table 6.3. Chi squared has a value of 0.17 that is not significant at conventional levels, indicating that the market participants do not appear to distinguish between the two groups in their assessment of the risks associated with CO2. The insignificant coefficients on CO2 in Estimation (4) and (5), Table 6.3 suggest that firms' over- (under)-compliance with the current emission standard does not affect the relationship between CO2 and the cost of equity, implying investors' holding of equities of firms undertaking proactive strategies in reducing carbon impacts is not adversely affected in terms of risk exposure.

In summary, the results in Table 6.3 indicate that the market pricing of carbon-associated risks is conditional on a firm's relative emission profile. However, as shown in Estimation (1), the magnitude of carbon intensity (CO2) is not priced for the full sample. The evidence that the effect of CO2 on equity financing is concentrated in relatively high-emitting firms is partially congruent with the extant industry and academic research implying that firms' exposure to carbon risks are asymmetric across industry sectors and, more importantly, are contingent on their relative capacity to pass on carbon costs (e.g., Clarkson et al., 2015; and IRRC Institute and Trucost, 2009).

Thus, the next subsection undertakes further analyses to investigate the effect of relative carbon performance on the cost of equity in an attempt to understand the role of firms' ability to pass on carbon costs within industries.

6.6 Further Analyses

6.6.1 The effect of relative carbon performance and surplus allowances

This section examines the impact of firms' relative carbon performance within industries and firms' over-compliance with policy expectation on the cost of equity. In projecting the potential impact of climate change on stock performance, industry research in investment strategies (e.g., Aulisi and Schuster, 2016) suggests that excluding carbon-intensive stocks from the equity portfolio may introduce undesired volatility exposure and tracking errors detracting from other investment objectives. To illustrate, 25 percent of the total weighting of the US S&P 500 comprises stocks from emission-intensive sectors, such as energy, utilities and industrials.

A coalition of investors (Cogan, 2006) suggests that low-emitting firms in carbon-intensive sectors could be rewarded by financial markets whereas high-emitting firms would be attributed more risk as a result of carbon pricing. Underlying this view is the argument that carbon risks are not merely driven by firms' absolute carbon intensity but are also contingent on policy outcomes, i.e., the allocation of allowances and the capacity to pass on carbon costs (IRRC Institute and Trucost, 2009). These arguments are consistent with the theoretical framework developed in management literature that explains how a proactive strategy may create competitive advantages based on the resource-based view of the firm (e.g., Hart, 1995). An equilibrium model derived by

Salop and Scheffman (1983) also provides an illustration of how a dominant firm may raise competitors' costs by over-complying with environmental standards. Along this line, Clarkson et al. (2015) suggest firms' relative carbon efficiency compared with sector peers is related to their ability to pass on the compliance costs. They find emissions from firms with relatively high carbon efficiency within sectors do not represent carbon costs as assessed by capital market participants supporting their argument that these costs are passed on. In addition, merely ranking firms based on the magnitude of carbon intensity may fail to capture the theoretical argument of the effect of a firm's capacity to adapt. Firms' capacity to adopt new technologies in their production activity and to evolve towards a green economy may reduce their risk towards climate change regulations from the perspectives of both investors and society.

This section investigates the association between firms' relative carbon intensity and the cost of equity financing to gauge whether the ability to pass on carbon costs reduces their carbon risks perceived by capital market participants. Similar to the method employed by Clarkson et al. (2015) to proxy for the capacity to pass on costs, this study implements an intra-industry decile rank of firms' carbon intensity on an annual basis to capture the relative carbon competitiveness of the firm (CO2PRO).

The analyses also investigate the effect of a surplus in the carbon allowance account to incorporate the impact of policy outcome as suggested by industry research (e.g., IRRC Institute and Trucost, 2009). As discussed in Section 6.5, surplus allowances represent firms' over-compliance with an acceptable level of emissions, reflected in the allowances granted by member states based on average carbon efficiency in industries and available clean technologies.

In particular, these analyses provide insights into whether investors condition their perception of carbon-related risks arising from firms' relative carbon performance on firms' over-compliance with existing regulatory requirements. The full regression model in Estimation (3), Table 6.4 is specified as following:

$$
\begin{aligned}
ICEC_{MPEG_{i,t}} = \alpha + \beta_1 \times CO2PRO_{i,t} + \beta_2 \times CO2SURPLUS_{i,t} \\
+\beta_3 \times (CO2PRO_{i,t} \times CO2SURPLUS_{i,t}) + \gamma_1 \times BETA_{i,t} + \gamma_2 \times SIZE_{i,t} + \gamma_3 \times BTP_{i,t} \\
+ \sum_{k=1}^{M} \delta_k \times CountryIndicator_{i,t}^{k} + \sum_{p=1}^{T} \theta_p \times IndustryIndicator_{i,t}^{p} \\
+ \sum_{q=1}^{9} \vartheta_q \times YearIndicator_{i,t}^{q} + \varepsilon_{i,t}
\end{aligned}
\quad (8)
$$

where $ICEC_{MPEG}$ is the implied cost of equity based on the Easton (2004) modified PEG estimate and the subscripts i and t represent the firm and the year, respectively; CO2PRO is the industry-year decile rank of the firm's CO2, where CO2 is measured as verified emissions scaled by sales revenue (tonnes/\$000) as previously defined; and CO2SURPLUS is a dummy variable equal to one if the firm has carbon allowances greater than carbon emissions, and zero otherwise. The equation also includes market beta, firm size, and book-to-price ratio as control variables as previously defined. In addition, industry, country and year indicators are included to control for any unobservable industry, regime and time fixed effects. In all regression analyses in Table 6.4, inferences are based on robust standard errors clustered at the firm level (Petersen, 2009).

Estimations (1) and (2) first investigate the effect of CO2PRO and CO2SURPLUS, respectively, on the cost of equity financing. Both estimations include firm-specific controls as well as year, industry and country fixed effects.

The results of Estimation (1) are presented in the first column of Table 6.4. The coefficient estimate of CO2PRO is positive (0.001) and statistically significant at the 10% level, implying that investors penalise firms with relatively high carbon risk profile compared with industry peers by demanding a higher rate of return on equity. This finding provides further support for recent arguments (e.g., Clarkson et al., 2015; Fullerton and Heutel, 2007; Grainger and Kolstad, 2010; and IRRC Institute and Trucost, 2009) that firms' exposure to carbon-related risks is affected by their ability to pass on carbon costs on as reflected in the intra-industry relative carbon intensity measure.

The results of Estimation (2) are shown in the second column of Table 6.4. The coefficient of CO2SURPLUS is not significant, indicating that whether the allowance is in surplus or deficit is not significantly related to the cost of equity. This suggests that over-compliance is not perceived to have an independent effect on firms' risk profiles.

The third column of Table 6.4 provides evidence on the interactions between CO2PRO and CO2SURPLUS according to the full specification in Equation (8). CO2PRO remains positively associated with $ICEC_{MPEG}$ at a similar level of significance with a larger economic magnitude as indicated by the point estimate (0.003) compared with Estimation (1).

Table 6.4. Regression results for implied cost of equity based on modified price earnings growth model on relative carbon performance

Independent variable	Predicted Sign	$ICEC_{MPEG}$		
		Est. (1)	Est. (2)	Est. (3)
CO2PRO	+	0.001*		0.003*
		(0.081)		(0.066)
CO2SURPLUS	?		0.003	0.016
			(0.521)	(0.116)
CO2PRO X CO2SURPLUS	–			-0.003*
				(0.090)
BETA	+	0.029***	0.026***	0.035***
		(<0.001)	(<0.001)	(<0.001)
SIZE	–	-0.006***	-0.009***	-0.009***
		(<0.001)	(<0.001)	(<0.001)
BTP	+	0.009***	0.011***	0.011***
		(<0.001)	(<0.001)	(<0.001)
Intercept		0.156***	0.208***	0.248***
		(<0.001)	(<0.001)	(<0.001)
Year, industry and country fixed effect		Included	Included	Included
Adj R-sqr		0.3258	0.3141	0.3068
Prob > F		(<0.001)	(<0.001)	(<0.001)

Notes: This table reports regression results for a sample of 2085 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, $ICEC_{MPEG}$, is the implied cost of equity capital based on the Easton (2004) modified PEG estimate at the end of the fiscal year. The main test variables are CO2PRO and CO2SURPLUS. CO2PRO is an industry-year decile rank of the firm's CO2, where CO2 is measured as verified emissions scaled by sales revenue (tonnes/$000), where verified emissions are the aggregated annual emissions at the listed controlling-entity level. CO2SURPLUS is a dummy variable equal to one if the firm has carbon allowances greater than carbon emissions, and zero otherwise. BETA is the slope coefficient from the regressions of a firm's excess returns on the monthly value-weighted market index excess returns over a rolling 60-month window ending in the current fiscal year where a minimum of 18 monthly returns is required during the 60-month window interval to calculate BETA. SIZE is the log of market capitalisation of the firm, measured at the beginning of the fiscal year. BTP the ratio of book value to market price of equity, measured at the beginning of the fiscal year. All results from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in all regression specifications; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

The coefficient on the interaction term is negative (-0.003) and marginally significant at the 10% level, implying the risks associated with relatively high carbon profile within industries is mitigated by holding surplus allowances. Nevertheless, from a statistical perspective, as indicated in the coefficient estimate on CO2PRO in Estimation (1) with a linear restriction (0.001, p=0.081), the risk is not fully eliminated. These findings corroborate earlier evidence (Table 6.3) suggesting that investors assess carbon-related risks conditional on firms' relative exposure. This also corresponds to prior research finding that firms have latent carbon liabilities arising from insufficient allocation of allowances and the limited ability to pass on costs (Clarkson et al., 2015). CO2SURPLUS is not found to be associated with the cost of equity in Estimation (3), similar to Estimation (2) where there is no interaction variable. All control variables are loaded with the expected signs in all regression models and are statistically significant at less than the 1% level. This indicates that the cost of equity measure employed exhibits the predicted relations with other common risk factors consistent with prior literature.

Thus far, two core findings arise from the analyses using the cost of equity estimate based on the Easton (2004) modified PEG measure. First, the market prices firms' risk from carbon intensity conditional on the firm's relative emission profile with emissions from high-emitting firms' associated with higher equity financing costs. Second, the cost of equity is higher for firms exhibiting a relatively high carbon risk profile; this is attributed to their limited ability to pass on costs. To determine the robustness of these results to the choice of the cost of equity measure, the next section repeats the analyses using an alternative implementation in estimating an implied cost of equity.

6.6.2 Alternative implied cost of equity estimate

This section employs an alternative cost of equity ($ICEC_{GLS}$) estimated using the discounted residual income model based on the industry method introduced by Gebhardt et al. (2001) (GLS method). The GLS method has been widely adopted in accounting and finance to obtain the expected return on equity (e.g., Chen et al., 2010; Lee et al., 2009; and Pástor et al., 2008). In an evaluation of five implementations of the 'implied cost of capital' method by Guay et al. (2011), the GLS method outperformed other models in their assessment. Similar to other approaches to estimating the cost of equity using accounting-based valuation models, the GLS model also computes the implied cost of equity as the internal rate of return that equates the discounted future cash flows to the current stock price. The key assumptions in the GLS implementation with a forecast horizon of 12 periods (as specified below) are that the forecasted return on equity (ROE) from period t+3 reverts to the industry median ROE at the end of the forecast horizon T=12 through simple linear interpolation, and that the terminal value beyond the forecast horizon is the present value of residual income in period T as a perpetuity assuming 100% dividend payout ratio (Gebhardt et al., 2001). As noted in Gebhardt et al. (2001), the underlying notion of an industry method is that firms tend to track industry peers' performance over the long-run. Thus mean reversion is employed to capture the erosion of individual firms' abnormal earnings in the long-term. Specifically, the implied cost of equity is imputed from equity prices and other variables specified in the GLS model using a forecast horizon of 12 periods:

$$P_t = BPS_t + \frac{(FROE_{t+1} - ICEC_{GLS})\, BPS_t}{(1+ICEC_{GLS})} + \frac{(FROE_{t+2} - ICEC_{GLS})\, BPS_{t+1}}{(1+ICEC_{GLS})^2} + TV,$$

$$\text{where, } TV = \sum_{i=3}^{T-1} \frac{(FROE_{t+i} - ICEC_{GLS})\, BPS_{t+i-1}}{(1+ICEC_{GLS})^i} + \frac{(FROE_{t+T} - ICEC_{GLS})\, BPS_{t+T-1}}{ICEC_{GLS}(1+ICEC_{GLS})^{T-1}}, \tag{9}$$

where Pt is the market price of the firm at the end of year t; $ICEC_{GLS}$ is the firm's implied cost of equity bounded by 0% to 100%; and $FROE_{t+1}$ to $FROE_{t+3}$ are estimated based on earnings per share forecasted by analysts reported in I/B/E/S; $FROE_{t+4}$ to $FROE_{t+12}$ are forecasted by median interpolation to the industry ROE, which is calculated at the end of each firm's fiscal year and forecasted as the moving median of the past five years of ROE for all firms within the same industry. Consistent with prior studies (e.g., Naiker et al., 2013), firms with a negative ROE are excluded in the calculation of the industry ROE median since these observations are not indicative of industry equilibrium rates of return in the long-term. Future book value per share is forecasted using clean surplus accounting, and is estimated as $BPS_{t+i} = BPS_{t+i-1} + FEPS_{t+i} - DPOUT \times FEPS_{t+i}$, where $i \geq 2$ and DPOUT is the dividend payout ratio calculated as DPS/EPS at the beginning of year t for firms with positive earnings. When EPS is less than zero, DPS is estimated as 6% of total assets per share at the beginning of year t. Consequently, after excluding observations with insufficient data to compute the cost of equity measure based on the GLS method, 1990 firm-year observations remain in the sample. The $ICEC_{GLS}$ provides a lower average of 0.105 compared with $ICEC_{MPEG}$ (0.128), consistent with prior studies finding that the GLS tends to provide a lower bound of the implied cost of equity measures (e.g, Dhaliwal et al., 2006; and Gode and Mohanram, 2013).

To assess whether the relationship between firms' carbon performance and cost of equity observed in this study is sensitive to the use of alternative measures of the cost of equity, the analyses reported in Tables 6.3 and 6.4 are re-estimated, replacing $ICEC_{MPEG}$ with $ICEC_{GLS}$ as the measurement of the cost of equity. Tables 6.5 and 6.6

report the results of repeating the estimations reported in Tables 6.3 and 6.4, respectively.

Overall, the results corroborate earlier findings. Specifically, consistent with results in Table 6.3, Estimation (1), Table 6.5 reveals that the CO2 does not load significantly, suggesting the absolute carbon intensity does not affect the cost of equity. Similarly, the coefficient estimate of CO2 in Estimation (2), Table 6.5 is positively associated with the dependent variable and statistically significant at the 5% level for high-emitting firms. Further, the results for the comparison of coefficient differences of CO2 between the high- and low-emitting groups (χ^2=5.07 p=0.029) suggests that more risk is attributed to emissions from high-emitting firms compared with those from low-emitting firms.

Further, results in Table 6.6 are qualitatively similar to those reported in Table 6.4. The results from Estimation (3), Table 6.6 indicate a positive association between CO2PRO and the cost of equity using $ICEC_{GLS}$ (0.002 p=0.021). A surplus account of emission allowances can mitigate, but not eliminate firms' risk exposure resulting from a high carbon risk profile relative to industry peers, as indicated by the negative loading on the interaction term between CO2PRO and CO2SURPLUS (p=0.063), and the positive point estimate on CO2PRO in Estimation (1), Table 6.6. Additionally, all control variables enter the regression models with the expected relationships with the dependent variable, thus indicating that firms' relative carbon performance is priced along with other common risk factors.

Table 6.5. Regression results for implied cost of equity based on GLS on carbon intensity

Independent variable	Predicted Sign	$ICEC_{GLS}$ Est. (1) Full Sample	Est. (2) High-Emitting	Est. (3) Low-Emitting	Est. (4) Deficit	Est. (5) Surplus
CO2	+	-0.010	0.052**	-0.001	0.020	-0.002
		(0.313)	(0.029)	(0.573)	(0.468)	(0.572)
BETA	+	0.004**	0.011***	0.125***	0.015***	0.015***
		(0.022)	(<0.001)	(0.004)	(<0.001)	(<0.001)
SIZE	–	-0.012***	-0.002***	-0.001	-0.002***	-0.002***
		(<0.001)	(<0.001)	(0.469)	(<0.001)	(0.002)
BTP	+	0.028***	0.003***	0.016***	0.002***	0.004***
		(<0.001)	(<0.001)	(<0.001)	(0.010)	(<0.001)
Intercept		0.340***	0.132***	0.106***	0.137***	0.124***
		(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
Year, industry and country fixed effect		Included	Included	Included	Included	Included
Subsample comparison of coefficients on CO2		–	χ^2=5.07 ** (*p*-value = 0.024)		χ^2=0.54 (*p*-value = 0.462)	
Adj R-sqr		0.1162	0.2671	0.2607	0.1683	0.1395
Prob > F		(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)

Notes: This table summarises regression results for a sample of 1990 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, $ICEC_{GLS}$, is the implied cost of equity capital derived from the Gebhardt et al. (2001) model at the end of the fiscal year. The first column presents the regression results based on the full sample. In the second and third columns, the sample was partitioned into two subsamples in accordance with their emission profile: high-emitting firms with carbon intensity greater than the sample mean and low-emitting firms with carbon intensity less than the sample mean. In the fourth and fifth columns, the sample was separated into two subgroups in accordance with their carbon allowances balances: firms with carbon allowances less than carbon emissions (Deficit) and firms with carbon allowances greater than carbon emissions (Surplus), respectively. The main test variable, CO2, represents carbon intensity measured as verified emissions scaled by sales revenue (tonnes/$000), where verified emissions are the aggregated annual emissions at the listed controlling-entity level. BETA is the slope coefficient from the regressions of a firm's excess returns on the monthly value-weighted market index excess returns over a rolling 60-month window ending in the current fiscal year where a minimum of 18 monthly returns is required during the 60-month window interval to calculate BETA. SIZE is the log of market capitalisation of the firm, measured at the beginning of the fiscal year. BTP the ratio of book value to market price of equity, measured at the beginning of the fiscal year. All results are from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in all regression specifications; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

Table 6.6. Regression results for implied cost of equity based on GLS on relative carbon performance

Independent variable	Predicted Sign	$ICEC_{GLS}$		
		Est. (1)	Est. (2)	Est. (3)
CO2PRO	+	0.001*		0.002**
		(0.066)		(0.021)
CO2SURPLUS	?		-0.003	0.003
			(0.110)	(0.403)
CO2PRO X CO2SURPLUS	–			-0.001*
				(0.063)
BETA	+	0.012***	0.008**	0.008***
		(<0.001)	(0.010)	(0.009)
SIZE	–	-0.005***	-0.005***	-0.005***
		(<0.001)	(<0.001)	(<0.001)
BTP	+	0.013***	0.013***	0.013***
		(<0.001)	(<0.001)	(<0.001)
Intercept		0.181***	0.180***	0.181***
		(<0.001)	(<0.001)	(<0.001)
Year, industry and country fixed effect		Included	Included	Included
Adj R-sqr		0.2212	0.2115	0.2118
Prob > F		(<0.001)	(<0.001)	(<0.001)

Notes: This table reports regression results for a sample of 1990 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, $ICEC_{GLS}$, is the implied cost of equity derived from the Gebhardt et al. (2001) model at the end of the fiscal year. The main test variables are CO2PRO and CO2SURPLUS. CO2PRO is an industry-year decile rank of the firm's CO2, where CO2 is measured as verified emissions scaled by sales revenue (tonnes/$000), where verified emissions are the aggregated annual emissions at the listed controlling-entity level. CO2SURPLUS is a dummy variable equal to one if the firm has carbon allowances greater than carbon emissions. BETA is the slope coefficient from the regressions of a firm's excess returns on the monthly value-weighted market index excess returns over a rolling 60-month window ending in the current fiscal year where a minimum of 18 monthly returns is required during the 60-month window interval to calculate BETA. SIZE is the log of market capitalisation of the firm, measured at the beginning of the fiscal year. BTP the ratio of book value to market price of equity, measured at the beginning of the fiscal year. All results from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in all regression specifications; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

In summary, the results from these further analyses suggest the findings are robust to the alternative implementation of estimating the cost of equity, thus reinforcing the earlier inferences that the cost of equity is higher for firms exhibiting relatively higher carbon risk profiles. Despite the frequent use of an ex-ante implied cost of equity, the use of analysts' earnings forecasts in deriving such estimates is subject to the caveat that noise in analysts' forecasts may contaminate the cost of equity measure (Gode and Mohanram, 2013). The next section conducts additional analyses to mitigate the possibility of spurious results arising from errors in analysts' forecasts.

6.6.3 Adjustment for predictable errors in analysts' forecasts

The implied cost of equity approach which uses an accounting-based valuation (analysts' forecast of earnings) is employed in the literature to avoid the limitation in using noisy average realised stock returns. However, recent research noted that the assumption that analysts' forecasts of earnings are unbiased estimates of expected earnings is weak, resulting in potential measurement errors in the implied cost of equity (Claus and Thomas, 2001; Easton and Sommers, 2007; El Ghoul et al., 2011; Williams, 2004). Prior research attributed errors in analysts' earnings forecasts to over and under reaction to certain information (Easterwood and Nutt, 1999). One source of errors in forecasts documented in previous studies is that analysts tend to be optimistically biased (e.g., Dechow and Sloan, 1997). Another source of forecast errors arises from their sluggishness in reacting to publicly available information, i.e., past earnings and returns leading to subsequent forecast revisions (e.g., Abarbanell, 1991; Lys and Sohn, 1990; and Stickel, 1991).

Hughes et al. (2008) develop a model to predict errors in earnings forecasts by synthesising the parameters from the two abovementioned sources. Utilising this model, Gode and Mohanram (2013) illustrate that the weak association between the implied cost of equity and realised returns observed in prior research could be improved by removing the predictable errors in analyst forecasts. Given that earnings forecasts provided by analysts represent a key construct to estimating the cost of equity implied in stock prices, to address the concern of measurement errors, following Naiker et al. (2013), the two cost of equity measures are re-estimated in this section. Specifically, the methodology operationalised by Gode and Mohanram (2013) is adopted to remove the predictable errors attributed to analysts' over and under reaction to past information as modelled by Hughes et al. (2008) using a two-step method. More specifically, in the first stage, the annual regression to predict forecast errors (SURP) specified in the following model employs over reaction variables including accruals (ACCR), long-term growth (LTG), sales growth (SGR), changes in PP&E (PPEG), changes in other long-term assets (OLAG) and under reaction variables including trailing returns (BHRet) and revision in analyst forecasts (REVEPS).

$$SURP_{1,i}/SURP_{2,i}=\alpha+\varphi_1 ACCR_i+\varphi_2 SGR_i+\varphi_3 LTG_i+\varphi_4 PPEG_i+\varphi_5 OLAG_i+\varphi_6 BHRET_i+\varphi_7 REVEPS_i+\varepsilon_i \quad (10)$$

where the dependent variable $SURP_{1,i}$ ($SURP_{2,i}$) is the difference between realised EPS for the next fiscal year (EPS1(2)) and the one-year-ahead (two-year-ahead) analysts' earnings per share forecasts reported in I/B/E/S (FEPS1(2)) for firm i, scaled by stock price; ACCR is total accruals calculated as earnings before extraordinary items minus cash from operations, deflated by lagged assets; SGR is growth in sales calculated from current and lagged sales; LTG is the median analyst long-term growth estimate; PPEG is growth in property, plant and equipment (PPE) calculated from current and lagged gross PPE; OLAG is growth in other long term assets (OLA) from current and lagged OLA, where OLA is measured as total assets minus current assets minus net PPE; BHRET is annual buy-and-hold returns for the 12 months prior to the estimation of implied cost of equity; and REVEPS is the difference between consensus mean analysts' 1-year ahead EPS forecast used for implied cost of equity estimation and the corresponding forecast at the beginning of the year, scaled by stock price. To predict forecast errors, annual regressions for $SURP_{1,i}$ and $SURP_{2,i}$ are based on 10 years of lagged data using independent variables measured at the same time as the underlying forecast. Hence, for prediction purposes, data for the required prediction variables are further obtained for the out-of-sample period from 1996 to 2005.

In the second stage, the coefficients from once-lagged and twice-lagged regressions are then multiplied by the realised values of the independent variables to purge the predicted forecast errors $PSURP_1$ ($PSURP_2$) from $FEPS_1$ ($FEPS_2$). For illustration, realised earnings forecast errors at the end of 2006 are regressed on the observable factors at the end of 2005 and the regression coefficients are then multiplied by the observable factors as of the end of 2006 to predict the error in earnings forecasts ($PSURP_1$) in $FEPS_1$ at the end of 2007. Subsequently, the adjusted one-year-ahead ($AFEPS_1$) and two-year-ahead ($AFEPS_2$) earnings forecasts correcting for predictable distortions are computed as ($FEPS_1$+ $PSURP_1$*PRICE) and ($FEPS_2$+ $PSURP_2$*PRICE), respectively. Consequently, both $ICEC_{MPEG}$ and $ICEC_{GLS}$ are re-estimated using $AFEPS_1$ and $AFEPS_2$, and labelled as $ICEC_{AMPEG}$ and $ICEC_{AGLS}$, respectively.

Accordingly, the next two sets of tests consider whether the earlier evidence is sensitive to any potential measurement error in implied cost of equity estimates arising from predictable noise in analysts' forecasts. In particular, using $ICEC_{AMPEG}$ as the dependent variable to replace $ICEC_{MPEG}$, Estimation (1), Table 6.7 re-estimates the analysis of Estimation (1), Table 6.3, and Estimations (2) to (4), Table 6.7 re-estimate the analysis of Estimations (1) to (3), Table 6.4, respectively. Similarly, Estimation (1), Table 6.8 re-estimates the analysis of Estimation (1), Table 6.5, and Estimations (2) to (4), Table 6.8 re-estimate the analysis of Estimations (1) to (3), Table 6.6, respectively, with $ICEC_{AGLS}$ specified as the dependent variable.

In both comparative analyses, CO2 continues to exhibit no significant impact on the cost of equity financing. The inference that the market perceives higher risks for firms with a relative high carbon risk profile as captured in CO2PRO, implying that the ability to pass on carbon costs shape investor perceptions, remains unchanged. The coefficient estimates obtained on all controls variables continue to load with the predicted signs and are statistically significant at similar levels compared to main analyses. Collectively, the results in Tables 6.7 and 6.8 alleviate concerns that the core evidence reported in Tables 6.3 and 6.4 arise from noise in analysts' forecasts.

Table 6.7. Regression results for adjusted implied cost of equity based on modified price earnings growth model on carbon performance

Independent variable	Predicted Sign	$ICEC_{AMPEG}$ Est. (1)	Est. (2)	Est. (3)	Est. (4)
CO2	+	-0.001			
		(0.260)			
CO2PRO	+		0.003*		0.003*
			(0.054)		(0.081)
CO2SURPLUS	?			0.005	0.022
				(0.524)	(0.237)
CO2PRO X CO2SURPLUS	−				-0.005*
					(0.080)
BETA	+	0.031***	0.026***	0.042***	0.055***
		(<0.001)	(<0.001)	(<0.001)	(<0.001)
SIZE	−	-0.027***	-0.015***	-0.015***	-0.014***
		(<0.001)	(<0.001)	(<0.001)	(<0.001)
BTM	+	0.022***	0.015***	0.013***	0.041***
		(<0.001)	(<0.001)	(<0.001)	(<0.001)
Intercept		0.550***	0.333***	0.311***	0.302***
		(<0.001)	(<0.001)	(<0.001)	(<0.001)
Year, industry and country fixed effect		Included	Included	Included	Included
Adj R-sqr		0.2613	0.3689	0.3249	0.3247
Prob > F		(<0.001)	(<0.001)	(<0.001)	(<0.001)

Notes: This table reports regression results for a sample of 2062 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, $ICEC_{AMPEG}$, is the implied cost of equity capital based on the Easton (2004) modified PEG estimate at the end of the fiscal year after adjusting for predictable errors in earnings forecasts. CO2PRO is an industry-year decile rank of the firm's CO2, where CO2 is measured as verified emissions scaled by sales revenue (tonnes/$000), where verified emissions are the aggregated annual emissions at the listed controlling-entity level. CO2SURPLUS is a dummy variable equal to one if the firm has carbon allowances greater than carbon emissions, and zero otherwise. BETA is the slope coefficient from the regressions of a firm's excess returns on the monthly value-weighted market index excess returns over a rolling 60-month window ending in the current fiscal year where a minimum of 18 monthly returns is required during the 60-month window interval to calculate BETA. SIZE is the log of market capitalisation of the firm, measured at the beginning of the fiscal year. BTP the ratio of book value to market price of equity, measured at the beginning of the fiscal year. All results from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in all regression specifications; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

Table 6.8. Regression results for adjusted implied cost of equity based on modified price earnings growth model on carbon performance

Independent variable	Predicted	$ICEC_{AGLS}$			
	Sign	Est. (1)	Est. (2)	Est. (3)	Est. (4)
CO2	+	-0.013			
		(0.525)			
CO2PRO	+		0.001*		0.001***
			(0.059)		(0.009)
CO2SURPLUS	?			-0.003	0.006
				(0.201)	(0.186)
CO2PRO X CO2SURPLUS	–				-0.001*
					(0.073)
BETA	+	0.006*	0.015***	0.010**	0.009***
		(0.062)	(<0.001)	(0.017)	(<0.001)
SIZE	–	-0.013***	-0.002***	-0.004***	-0.001**
		(<0.001)	(<0.001)	(<0.001)	(0.014)
BTM	+	0.027***	0.005***	0.010***	0.022***
		(<0.001)	(<0.001)	(<0.001)	(<0.001)
Intercept		0.362***	0.112***	0.166***	0.097***
		(<0.001)	(<0.001)	(<0.001)	(<0.001)
Year, industry and country fixed effect		Included	Included	Included	Included
Adj R-sqr		0.1127	0.2968	0.2685	0.2813
Prob > F		(<0.001)	(<0.001)	(<0.001)	(<0.001)

Notes: This table reports regression results for a sample of 1977 firm-year observations of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable, $ICEC_{GLS}$, is the implied cost of equity capital derived from the Gebhardt et al. (2001) model at the end of the fiscal year after adjusting for predictable errors in earnings forecasts. CO2PRO is an industry-year decile rank of the firm's CO2, where CO2 is measured as verified emissions scaled by sales revenue (tonnes/$000), where verified emissions are the aggregated annual emissions at the listed controlling-entity level. CO2SURPLUS is a dummy variable equal to one if the firm has carbon allowances greater than carbon emissions, and zero otherwise. BETA is the slope coefficient from the regressions of a firm's excess returns on the monthly value-weighted market index excess returns over a rolling 60-month window ending in the current fiscal year where a minimum of 18 monthly returns is required during the 60-month window interval to calculate BETA. SIZE is the log of market capitalisation of the firm, measured at the beginning of the fiscal year. BTP the ratio of book value to market price of equity, measured at the beginning of the fiscal year. All results from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in all regression specifications; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

6.7 Robustness Checks

In the final section of data analyses, additional sets of sensitivity tests are undertaken to examine the robustness of the core findings. In particular, various econometric models are re-estimated to address issues relating to reverse causality, country representation, time period, and industry membership. In each set of further considerations, $ICEC_{MPEG}$ and $ICEC_{GLS}$ are used as the dependent variables in the first and second estimation, respectively. Overall, the results from these additional robustness tests reported in Table 6.9 suggest these augmentations do not appear to affect the primary results and inferences.

The strategy adopted to operationalise an empirical construct of firms' relative carbon risk profile is based on the historical emission level published via the transaction log under the EU_ETS. Thus, the main analyses focus on publicly available contemporaneous emission information, based on the appealing rationale that the variable captures investors' use of historical emission levels to derive an unbiased anticipation of firms' carbon risk profile and to adjust the required rate of return according to the perceived level of risk. In contrast, it is not intuitive to assume that a lower cost of equity leads to a lower contemptuous emission profile. In particular, firms' investment in green technologies represents long-term investment decisions that may be irreversible in the short-term. Nevertheless, the first set of sensitivity analyses are performed to reduce the possibility that the results are driven by potential reverse causality. Accordingly, lagged carbon measures are used as explanatory variables to reflect expectations established from historical information.

The results of replacing CO2PRO with one-year lagged values in the econometric models are reported in Estimation (1), Table 6.9. Evidence of a significant positive association between CO2PRO and $ICEC_{MPEG}$ at the 5% level remains robust in Estimation (1), Table 6.9, implying market pricing of carbon risks using firms' relative carbon performance. Consistently, an insignificant estimate on the contemporaneous surplus allowances (CO2SURPLUS) is reported in the first column. Of note, the coefficient estimate on the interaction variable between lagged CO2PRO and contemporaneous CO2SURPLUS is not significant in contrast to the core results reported in Table 6.4 where it was marginally significant at the 10% level.

Similarly, using $ICEC_{GLS}$ as the dependent variable, Estimation (2) provides evidence and inferences that the market accepts a lower risk premium for firms emitting significantly less carbon relative to industry counterparts. Further, results for Estimations (3) and (4), which also substitute the CO2SURPLUS with lagged values, are qualitatively similar to those reported in Estimations (1) and (2), respectively. Overall, these estimations provides further evidence consistent with the main inference that a high carbon risk profile relative to industry peers leads to a higher rate of required return on equity. Again, the coefficients on the lagged interaction variables remain insignificant in these specifications compared with weakly significant coefficients in core results.

The next group of sensitivity analyses address concerns that shifts in the cost of equity are systematically driven by country-level corporate governance, time-period and industry representation, although these issues are partially alleviated by controlling for country, industry and year fixed effects in all regression models in the main analyses.

Results from these additional tests are qualitatively similar to the core results reported in Table 6.4 and robust to alternative design choices.

First, prior literature finds evidence of a lower cost of equity associated with country-level governance mechanisms including stronger capital market regulations (Daouk et al., 2006), legal protection (e.g., La Porta et al., 2002) and disclosure requirements (Hail and Leuz, 2006). Hence, to reduce the possibility of spurious results that may arise from stronger country-level governance, the first set of tests focuses on a subsample of firms from the UK which is perceived to have better investor protection (World Bank Group, 2016) and has higher carbon disclosure requirements as discussed in Section 1.2.

The coefficient for CO2PRO is positive and statistically significant when using $ICEC_{MPEG}$ and $ICEC_{GLS}$ in Estimations (5) and (6), respectively, reinforcing the earlier inference (Section 6.6.1) that a higher carbon risk profile relative to industry norm increases the cost of equity. Of note, the magnitude of CO2PRO is also larger in Estimations (5) and (6) than in Estimation (1), Tables 6.4 and 6.6, respectively. This finding is also consistent with prior studies suggesting a stronger association to be observed in a regime where carbon regulation and enforcement are more stringent (Clarkson et al., 2015).

Table 6.9. Robustness Checks for implied cost of equity estimates based on Easton (2004) and GLS (2001)

Independent variables	Lagged CO2PRO		Lagged CO2PRO Lagged CO2SURPLUS		UK Sample		Excluding 2008 and 2012		Excluding Financials and Utilities sectors	
	Est. (1)	Est. (2)	Est. (3)	Est. (4)	Est. (5)	Est. (6)	Est. (7)	Est. (8)	Est. (9)	Est. (10)
CO2PRO	0.003**	0.002**	0.003**	0.001**	0.005*	0.003*	0.002*	0.002**	0.003**	0.002**
	(0.027)	(0.045)	(0.035)	(0.023)	(0.055)	(0.089)	(0.088)	(0.022)	(0.039)	(0.011)
CO2SURPLUS	0.005	0.001	0.004	0.003	0.025	0.030	0.017	0.004	0.016	0.002
	(0.617)	(0.765)	(0.675)	(0.411)	(0.207)	(0.103)	(0.123)	(0.345)	(0.199)	(0.615)
CO2PRO X CO2SURPLUS	0.001	-0.001	0.001	-0.001	-0.005*	-0.006*	-0.003*	-0.002*	-0.002	-0.001
	(0.619)	(0.283)	(0.752)	(0.121)	(0.091)	(0.085)	(0.097)	(0.059)	(0.446)	(0.209)
BETA	0.032***	0.011***	0.034***	0.009***	0.022**	0.013*	0.025***	0.007***	0.030***	0.013***
	(<0.001)	(0.001)	(<0.001)	(<0.001)	(0.011)	(0.091)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
SIZE	-0.006***	-0.006***	-0.007***	-0.008***	-0.005**	-0.006***	-0.010***	-0.006***	-0.007***	-0.006***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(0.048)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
BTP	0.010***	0.016***	0.010***	0.019***	0.010***	0.008*	0.011***	0.010***	0.010***	0.019***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(0.087)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
Intercept	0.130***	0.203***	0.144***	0.225***	0.187***	0.214***	0.260***	0.191***	0.143***	0.202***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
N	1451	1385	1033	988	435	409	1656	1584	1812	1728
Adj R-sqr	0.2951	0.2528	0.2972	0.2689	0.2970	0.2800	0.2812	0.2627	0.2918	0.2071
Prob > F	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)

Notes: This table reports regression results of robustness analyses for a sample of European companies regulated under the EU_ETS from 2006 to 2015. The dependent variable in Estimations (1), (3), (5), (7) and (9) is, $ICEC_{MPEG}$, the implied cost of equity capital based on the Easton (2004) modified PEG estimate at the end of the fiscal year. The dependent variable in Estimations (2), (4), (6), (8) and (10) is, $ICEC_{GLS}$, the implied cost of equity capital derived from the Gebhardt et al. (2001) model at the end of the fiscal year. Results in the first two estimations are from regressions of the cost of equity estimate on lagged CO2PRO. Results in Estimations (3) and (4) are from regressions of the cost of equity estimate on lagged CO2PRO and CO2SURPLUS. Estimations (5) and (6) use a subsample of firms operating in the UK. Estimations (7)-(8) and (9)-(10) exclude years 2008 and 2012, and financials and utilities sectors, respectively. CO2PRO is an industry-year decile rank of the firm's CO2, where CO2 is measured as verified emissions scaled by sales revenue (tonnes/$000), where verified emissions are the aggregated annual emissions at the listed controlling-entity level. CO2SURPLUS is a dummy variable equal to one if the firm has carbon allowances greater than carbon emissions, and zero otherwise. BETA is the slope coefficient from the regressions of a firm's excess returns on the monthly value-weighted market index excess returns over a rolling 60-month window ending in the current fiscal year where a minimum of 18 monthly returns is required during the 60-month window interval to calculate BETA. SIZE is the log of market capitalisation of the firm, measured at the beginning of the fiscal year. BTP the ratio of book value to market price of equity, measured at the beginning of the fiscal year. All results from ordinary least square regressions where standard errors are clustered at the firm level. Year, industry and country fixed effect are included in all regression specifications; all variables are winsorised at the top and bottom 1% level to avoid any undue influence from the outliers; ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.

The next group of tests repeats the main analyses excluding the years 2008 and 2012 to mitigate the potential undue bias driven by extreme variation in the cost of equity during the global financial crisis and Eurozone crisis. As reported in Estimations (7) and (8), CO2PRO is positively associated with $ICEC_{MPEG}$ and $ICEC_{GLS}$, respectively. Thus the inferences remain unaltered when the analyses are confined to a sampling period that excludes the financial crises.

In the final set of tests, firms operating in the financials and utilities sectors are excluded to reduce any undue influence from variations in requirements specific to those industries. The results of the sensitivity check are presented in Estimations (9) and (10), Table 6.9. The coefficients for CO2PRO are positive and statistically significant and of a similar magnitude to the core results reported in Tables 6.4 and 6.6, corroborating earlier evidence of the market pricing of carbon risks. Thus, the core evidence and conclusions appear robust to the exclusion of certain industry sectors and other considerations.

6.8 Summary

This study investigates whether and how corporate carbon performance affects the market's perception of firms' risk profile manifested in the cost of equity. While the conventional economic view suggests that investment in environmental performance represents costs to firms because of a large initial capital expenditure, there is emerging evidence indicating an informational role of firms' carbon performance in the equity market contributing to firm value. Thus, this study focuses on an important but under-investigated valuation role of carbon performance information. Specifically, this study examines whether information about firms' carbon performance affects investors' perception of firm risks captured in an ex-ante cost of equity implied from stock prices and earnings forecasts.

Based on a capital market equilibrium with incomplete information modelled by Merton's (1987) and Heinkel et al.'s (2001) theoretical framework of exclusionary green investing, if carbon performance information provides more firm-specific information regarding firms' future carbon risk exposure, firms exhibiting high carbon risk are predicted to have a higher cost of equity because of higher perceived risk and lower investor preference. This study also considers whether the effect of carbon performance on the cost of equity is more pronounced for high-emitting firms. Further, it examines the effect of firms' carbon profile relative to industry peers to shed light on the effects on the cost of equity, considering a firm's ability to pass on carbon-related costs. As such, this study seeks to advance knowledge by providing direct empirical evidence on the cost of equity effects of carbon performance information in an attempt to identify whether the benefits of demonstrated leadership in managing carbon impacts and thereby enhancing the firm value, is reflected in the cost of equity.

This study undertakes a variety of multivariate regression analyses using an implied cost of equity measure to examine the market's perception of carbon risks. The analyses are performed using a sample of firms regulated under the EU_ETS from 2006 to 2015 and controlling for other firm-level characteristics as well as country, industry and time fixed effects. This study finds that the magnitude of firms' emission profile neither increases nor decreases the cost of equity. However, when the sample is partitioned between high-emitting and low-emitting firms, a positive association of firms' emission profile with the cost of equity is observed for high-emitting firms, consistent with predictions, while emissions from low-emitting firms do not appear to affect the cost of equity. This implies that the market's assessment of carbon risks is conditional on a firm's relative emission profile. This study further investigates the impact of firms' relative carbon risk profile on the cost of equity. As expected, a higher intra-industry rank of firms' emission intensity, which is a proxy for firms' limited ability to pass on carbon costs, increases the cost of equity after controlling for country, industry, and year effects in addition to firm-level attributes.

Collectively, the results from this study support the hypothesis that carbon performance information influences investors' perceptions of firm riskiness. Further, to ensure the robustness of these inferences, this study employs an alternative implementation in estimating the cost of equity using the Gebhardt et al. (2011) industry method and adjustments for predictable errors in analysts' forecasts. Specifically, this addresses the concern of potential measurement errors in the cost of equity estimates. The core results are robust to these alternative constructs. Additional sensitivity tests indicate that these results remain robust to the use of lagged carbon variables and using more stringent samples in regression specifications. This evidence confirms the role of firms' relative carbon profile in explaining cross-sectional variations in the cost of equity. It thus provides a more comprehensive understanding of the informational role of corporate carbon performance in affecting firm value in a carbon constrained future.

Overall, this study implies that capital market participants view information of corporate carbon performance as relevant and adjust the required rate of return accordingly, especially for firms with high emission profiles and limited capacity to pass on costs. This study thus contributes to the expanding carbon research by providing evidence of value enhancement manifesting in a lower cost of equity for firms that demonstrate leadership in carbon efficient operations within industries. The next chapter discusses practical and policy implications of findings from this thesis and identifies caveats and limitations in the study with suggested directions for future research.

CHAPTER 7

CONCLUSIONS

7.1 Summary of Findings

This thesis has conducted two related lines of research into the stock market effects of corporate carbon performance. Chapters 5 and 6 examined the informational role of corporate carbon performance in the market valuation of firms. In particular, Chapter 5 investigated the impact of corporate carbon performance information on firms' information environment. Chapter 6 estimated the impact of corporate carbon performance on the market's assessment of firms' risk profile reflected in the cost of equity. Utilising a sample of firms regulated under the EU_ETS during 2006 to 2015, this thesis provides new empirical evidence of the value relevance of corporate carbon performance information in the stock market.

Chapter 5 investigated the effect of corporate carbon performance on firm-specific information. The study utilised carbon information that was manually compiled from the transaction log for publicly listed firms regulated under the EU_ETS to measure corporate carbon performance and carbon competitiveness within industries using an annual intra-industry decile rank of the carbon metric. Based on stakeholder theory and the resource-based view of the firm, this study posited that corporate carbon performance represents a firm-specific resource and thus results in a greater amount of firm-specific information impounded in stock prices. Using a standardised measure of the relative distribution of firm-specific information flows to industry- and market-wide information, as summarised in stock return synchronicity, the empirical results provide evidence that corporate carbon performance has a significant impact on firms' information environment. Specifically, firms exhibiting a high emission profile have higher stock return synchronicity, indicating less firm-specific information incorporated in their stock prices. Further, the study also finds that corporate emission intensity increases the synchronicity measure, after controlling for a number of market- and industry-wide factors, as well as firm-level attributes. This suggests that corporate carbon performance serves an important information role by impounding more firm-specific information into stock prices. In addition, this study finds that firms' relative carbon competitiveness reduces the synchronicity of stock returns, suggesting that leadership in managing carbon impacts relative to industry peers represents firm-specific information beyond industry- and market-wide information. Moreover, this study provides evidence that both carbon intensity and carbon risk profile are positively (negatively) associated with the systematic (idiosyncratic) component of stock returns, respectively. This finding corroborates the abovementioned evidence that better carbon performance results in more firm-specific information impounded in stock prices. These inferences were confirmed for alternative models using lagged carbon variables in addition to more stringent samples controlling for extreme year and industry effects.

Chapter 6 examined the market assessment of firms' carbon risk profile. Using an ex-ante cost of equity imputed from current stock prices and earnings forecasts, this study provides empirical evidence on the effect of a firm's carbon risk profile on its expected return, an external source of firm value enhancement. First, this study finds that the magnitude of carbon intensity neither increases nor decreases a firm's cost of equity. However, a significant positive association between emission intensity and cost of equity was found for a subsample of high-emitting firms, implying the market's pricing of firms' emissions is conditional on their relative emission profile.

The second study also investigated the impact on the cost of equity of firms' ability to pass on carbon costs. Following Clarkson et al. (2015), firms' relative carbon performance within industries was used as a proxy for their ability to pass on carbon-related compliance costs. That is, a high carbon emission profile relative to industry peers represents less capability to pass on carbon costs. The empirical results generally show that a higher emission profile relative to industry peers is associated with a significantly higher cost of equity, which corroborates the previous finding that the market's pricing of carbon risks is conditional on firms' relative emission profile. A range of additional tests were performed using an alternative research design including a different method in estimating the cost of equity measure, corrective adjustments in earnings forecasts in imputing the cost of equity, as well as a series of robustness tests using lagged carbon variables and other specifications for samples further restricted to certain industries, or a particular country or period. The results of these additional tests were similar to those of the initial analyses, thus providing evidence of the robustness of the main findings.

In summary, the results from the empirical studies in Chapters 5 and 6 confirm an important information role of corporate carbon performance in the stock market by impounding more firm-specific information into stock prices and reducing the market's perception of firm riskiness reflected in the cost of equity.

7.2 Potential Limitations

This thesis employed the capital market research method to empirically investigate the information usefulness from the perspective of market participants. However, capital market research is a joint test of market efficiency and model specification. Therefore this thesis does not consider how investors respond to carbon information or how they incorporate it in their assessment of the firm value.

While this thesis provides comprehensive and robust evidence on the important informational role of corporate carbon performance, there are two constructs to these analyses that may potentially limit the robustness or generalisation of the results. First, an implied approach to estimate the cost of equity was employed because of the advantage of avoiding the use of realised returns. Hence, this approach does not require a long window of returns to extract a good proxy for expectations, while allowing for short-term changes in growth information. Although the results are robust to alternative calculations of cost of equity estimates, it is acknowledged that there is controversy in the literature in relation to the validity of cost of equity estimates based on forecasts of accounting measures. As more time series observations become available from the operation of an enacted ETS, future research may further validate the measures and corroborate the association between corporate carbon performance information and the cost of equity using realised returns to proxy for expected returns. In addition, as the cost of equity measure employed in this thesis relied on earnings forecasts provided by I/B/E/S analysts, the inferences might not be generalisable to firms that are not followed by analysts, for which investors potentially incur higher information costs to search privately for independent sources of disclosure (Berthelot et al., 2003).

Second, this thesis examines the informational role of carbon performance information in the context of the EU_ETS. The carbon metrics examined may also proxy for other governance mechanisms (c.f., De Villers et al., 2011) . Though the research design enhanced the empirical power of the analyses by focusing on a research setting where carbon emissions are regulated and carbon disclosures are verified and mandated through an enacted ETS, this may limit the generalisability of the findings to other regimes with different levels of regulatory enforcements and incentives for voluntary disclosure.

7.3 Contributions

Existing literature shows the valuation relevance of emission information in the equity market and suggests that a higher emission level decreases share prices (e.g., Clarkson et al., 2015; Griffin et al., 2017; and Matsumura et al., 2014). While these studies are unambiguous in suggesting that emission information affects firm value, they do not explicitly consider a potentially important but under-explored valuation role of corporate carbon performance in affecting firms' information environment to establish the route by which it affects firm value. Despite an increasing interest in understanding the usefulness of emission information, there is little empirical evidence on the impact of corporate carbon performance information on the relative distribution of price-sensitive information flows and the cost of equity, an important channel through which investors may reward firms for their efforts in reducing carbon impacts.

First, this thesis contributes to the environmental accounting literature by providing empirical evidence that carbon information under an existing ETS affects firms' information environment. The research scope of previous studies examining the broader notion of environmental performance is limited to a single industry based on the reasoning that social interests may vary across industries (e.g., Holmes, 1977; and Ingram, 1978). Employing a regulatory context under an enacted ETS, this thesis also expands the research scope of previous literature (e.g., Chen and Gao, 2012) by employing a carbon metric that is regulated by government and applicable across industries. In particular, this thesis furnishes evidence of intra-industry transfer of information to firms with higher relative carbon profiles.

Second, this thesis contributes to the extant literature by providing additional insights into an under-explored valuation role of corporate carbon performance. More specifically, it provides empirical evidence that information about corporate carbon performance contained in an existing emission trading scheme serves an information role in the equity market by impounding more firm-specific information into stock prices. Overall, this thesis provides empirical evidence of the importance of corporate carbon performance in explaining stock price informativeness, thus contributing to a better understanding of the information usefulness of corporate carbon performance in the capital market.

Finally, this thesis also contributes to the development of theory by providing empirical evidence on one source of the information content of corporate carbon performance. It demonstrates the benefit through a reduction in the cost of equity of a firm's leadership in carbon management, thus contributing to a better theoretical understanding of one route through which this information improves firms' information environment and enhances firm value.

7.4 Implications

In addition to documenting the above relationships, findings from this thesis also have important policy implications for stock market regulators and policy makers in their future considerations of carbon disclosure requirements, as well as practical implications for corporate executives in making strategic financial decisions.

The findings from this thesis can inform financial regulators and policy makers in their considerations of carbon disclosure requirements in the context of public debate of whether disclosure of corporate carbon performance information should be mandatory. Regulators and standard setters are concerned that an increase in the volume of disclosures over time may result in an overload of irrelevant information. This, in turn, reduces the effectiveness of corporate disclosures and increases costs arising from the extensive resources devoted to the collection, compilation and dissemination of such information. Establishing the materiality of such information in a capital market setting provides confirmatory evidence of the relevance of carbon disclosures in the form provided under EU_ETS. The empirical evidence in this thesis suggests that carbon disclosures obtained from an operating ETS complement the existing financial disclosure requirement by providing investors with incremental firm-specific information, reassuring regulators and standard setters that the information about corporate carbon performance plays a useful informational role in the capital market.

Using a multi-industry design, this thesis explicitly addresses whether and how corporate carbon competiveness within industries affects the distribution of price-sensitive information flows. The empirical evidence provided on the greater amount of firm-specific information from a firm’s leadership in carbon management relative to industry peers, compared with market and industry-level information flows, informs the policy debate by providing insights into the comparability of a carbon performance measure under the actual implementation of an existing ETS.

Further, this thesis empirically validates the argument of asymmetric exposure to carbon constraints between industry sectors by showing a higher cost of equity attached to firms with high carbon intensity relative to their industry peers. Given the level of competitiveness within industries, higher relative carbon intensity is interpreted as indicative of a limited capacity to pass on carbon compliance costs. An objective of prescribing carbon disclosures is to empower investors with transparent carbon information in assessing firms' carbon risks, where comparability of carbon performance information constitutes a key attribute of information usefulness to investors. This thesis is therefore potentially helpful to policy makers in the development of a comparable and standardised carbon metric by providing evidence that investors view firms' carbon competitiveness as relevant information specific to a firm. In particular, the empirical results show the important informational role of a reliable metric obtained from an existing ETS, enabling investors to benchmark firms' carbon performance against industry peers, consistent with the desired attribute of commensuration (Kolk et al., 2008).

Findings from this thesis also contribute to the public debate on whether the marginal costs from investment in carbon technologies outweigh the marginal benefits by showing that firms' carbon competitiveness within industries can enhance firm value through a lower cost of equity. Establishing that the cost of equity is a channel through which carbon risk management affects firm value also provides practical implications for strategic investment choices to managing carbon impacts by corporate decision makers. The potentially large amount of initial outlay in low-emission investment poses a challenge to the economic sustainability of such investments. This thesis documents a potential benefit of lower financing costs in the equity market that corporate executives can include in their evaluation of projects beyond a consideration of accounting earnings. Firms' efforts in reducing their carbon impacts not only benefit society, but also enhance investors' perception of firm riskiness manifested in the cost of equity. Finally, this thesis also has implications for portfolio management in relation to the construction of portfolios to address the preferences of eco/green investors by tracking firms exhibiting leadership in managing carbon impacts compared with industry peers.

7.5 Future Research

Previous studies suggest that the valuation impact of carbon performance may differ because of variations in regulations and societal pressure (e.g., Clarkson et al., 2015; and Sharfman and Fernando, 2008) as well as across cultures and religions (e.g., Salaber, 2007). Therefore, further research could be extended to a global sample of regimes, subject to data becoming available through the wider implementation of carbon emission trading schemes

This thesis focuses on the emission and allowance data in the transaction log under the EU_ETS in measuring corporate carbon performance. The transaction log affords a rich set of information other than the variables used in this research, such as whether the firm has failed to surrender sufficient allowances at the end of the compliance cycle. Future research may thus investigate the usefulness of other types of information. In addition, it may also be useful to investigate, for example, whether corporate voluntary disclosure of carbon-related issues or a long-term strategy to managing carbon impacts provide further incremental or substitutional information to mandatory disclosure under the EU_ETS at the branch level.

Finally, another possibility for future research would be to investigate the perception of risk profile from the perspective of debtholders. Further research could provide insights into whether carbon information from an enacted ETS is priced differently by debt markets compared with equity markets.

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