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Carbon risk and corporate capital structure

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ABSTRACT

This research exploits Australia's ratification of the Kyoto Protocol, which mandates the country to reduce carbon emissions, thereby exposing Australian firms to increased carbon risk, as a quasi-natural experiment to examine the causal effect of carbon risk on firm capital structure. We find that the Kyoto Protocol ratification leads to a decrease in financial leverage of heavy carbon emitting firms and such a decrease is more pronounced for financially constrained firms. Further analysis indicates that increased carbon risk leads to higher financial distress risk, which motivates firms to decrease financial leverage.

> "Our customers mining for coal, oil and gas, as well as those in coal-fired electricity generation, and related industries, are increasingly exposed and may experience transition risk as a result of decreasing demand for fossil fuels and increasing demand for clean energy. We encourage customers in these sectors to plan for, and start making, the necessary changes for climate adaptation." (Shayne Elliott, Chief Executive Officer of the Australia and New Zealand Banking Group Limited).[1]

1. Introduction

How do the costs associated with environmental responsibility in general and carbon risk, which is a firm's financial vulnerability to the transition away from a fossil fuel-based to a lower-carbon economy, in particular affect firm capital structure? Previous studies suggest that firms with poorer environmental records, such as higher carbon emissions, or greater exposure to environmental risks incur higher costs of capital (Sharfman and Fernando (2008), Chava (2014)), and have inferior financial and investment performance (Dowell et al. (2000), Konar and Cohen (2001), Stefan and Paul (2008), Matsumura et al. (2013)). The recent adoption of more stringent carbon control regulations increases carbon risk and the costs to manage carbon emissions (hereafter referred to as carbon costs) for heavy carbon emitters, such as firms operating in the energy, materials, or utilities industries (Balachandran and Nguyen (2018)). Nonetheless, whether and how carbon risk affects firm financial policies remain under-researched (Diaz-Rainey et al. (2017)). In this study, we exploit a major carbon regulatory change, the Kyoto Protocol ratification (KPR) by Australia, as a shock to carbon risk faced by firms to examine their responsive financing choices.

The relation between carbon risk and capital structure is unclear *ex ante*. An increase in carbon risk may discourage firms from using carbon-intensive technologies while encouraging them to voluntarily switch to more carbon-efficient ones. Reduced carbon

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[1] Available at https://www.theguardian.com/business/2016/dec/17/adani-coalmine-anz-chief-suggests-bank-would-not-finance-carmichael-project. Last accessed on November 4, 2018.

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emissions may lower firms' operating risk and facilitate their access to external capital markets, potentially leading to an increase in debt financing and higher financial leverage (Sharfman and Fernando (2008)). However, it could be challenging for firms with high carbon emissions by nature to reduce carbon costs when they need to do so, such as during economic downturns. Thus, carbon costs can become fixed in nature that increase firms' operating leverage and financial distress risk. The trade-off theory of capital structure posits that firms choose the mix of debt and equity financing to balance the tax shield benefits and the risk and costs of financial distress associated with debt financing (Kraus and Litzenberger (1973), Scott Jr (1976), Bradley et al. (1984), Graham (2003)). To the extent that carbon risk adversely affects corporate performance, thereby decreasing the tax shield benefits while increasing financial distress risk, it will lower firms' optimal financial leverage ratios, motivating them to reduce debt in the capital structure. Against this backdrop, we are interested in examining empirically the relation between carbon risk and firm capital structure.

An investigation of the effect of carbon risk on firm capital structure is subject to at least two empirical challenges. First, the decisions on the level of corporate exposure to carbon risk and financing choices may be jointly determined or both of them may be correlated with unobservable firm characteristics, raising an endogeneity concern that renders the parameter estimates biased and inconsistent. Second, the lack of firm-level carbon-related data, such as greenhouse gas (GHG) emissions or energy consumption (Konar and Cohen (2001)), typically results in small sample size, which prevents researchers from drawing valid inferences or generalizing the findings. Moreover, even if the carbon emission data were available, they might reflect current or past carbon performance, whereas carbon risk, which indicates a firm's financial vulnerability to the transition from a fossil fuel-reliant stage to a lower-carbon one, is forward-looking and hence unlikely to be directly observable.

We address the aforementioned challenges in two ways. First, to alleviate endogeneity concern, we exploit the KPR by Australia in December 2007 as a plausibly quasi-natural experiment. The Kyoto Protocol is an international agreement whereby participating countries commit to reduce carbon emissions to satisfy national reduction targets (UNEP (2006)). Under the Kyoto Protocol, Australia is required to restrict its average annual emissions over the period 2008–2012 to 8% above its 1990 level.[2] Moreover, the KPR was the first act of the former Prime Minister Kevin Rudd after being sworn in and widely regarded as the starting point of a flurry of stricter carbon control regulations on Australian businesses (Balachandran and Nguyen (2018)). The KPR, therefore, is arguably an exogenous shock to the carbon risk faced by heavy carbon emitters (heavy emitters), which allows us to identify a causal relation between carbon risk and firm capital structure.

Second, to address the small sample size problem, we rely on the carbon emission nature of a firm's industry, that is, the industry level of carbon emissions and energy consumption, to identify heavy emitters. In particular, we sort firms into either heavy or light emitter subgroups based on their industry classifications. Since industry classification is generally independent of individual firm characteristics, it can alleviate any concern that a firm may make decision on the level of carbon risk exposure conditional on its level of financial leverage or both firm financial leverage and its level of carbon risk exposure are correlated with other firm attributes (Krüger (2015)).

To validate our arguments for the exogeneity of the KPR by Australia and the relevance of using industry-level carbon emissions for classification purpose, we examine the market reaction to the announcement of KPR by calculating the cumulative abnormal stock return (CAR) around the announcement day. We find negative CAR for the average firm. Further subsample analysis indicates that the negative market reaction is concentrated among heavy emitters, while the market reaction is statistically insignificant for light emitters. This evidence indicates that the market, at least, had not fully anticipated the KPR by Australia and/or the level of carbon risk faced by heavy emitters following the KPR.

Next, we employ the difference-in-differences (DID) analysis framework to track the evolvement of financial leverage of heavy emitters relative to that of light emitters from before to after the KPR. We find that heavy emitters experience a decrease in both book and market leverage following the KPR. Since our DID regressions control for firm and year fixed effects, the negative impact of KPR on financial leverage of heavy emitters is within-firm over time and hence unlikely to be driven by firm or industry heterogeneities (Wooldridge (2012)).

Although using industry-based classification of heavy and light emitters can mitigate the small sample concern due to the lack of firm-level carbon emission data, it is possible that our results merely capture industry effects rather than firms' exposure to carbon risk. To rule out this possibility, we rerun our tests using two alternative proxies for firm-level carbon risk exposure. First, we exploit the National Greenhouse and Energy Reporting (NGER) Act 2007, which mandates businesses that have carbon emissions above a certain threshold to report their carbon emissions and energy consumption to the government that subsequently discloses them to the public. The NGER Act serves to inform Australian environmental regulators for the implementation of the KPR and other climate change policies. Since the NGER-mandated firms are the biggest emitters, hence most vulnerable to carbon risk, we consider these firms as the treated ones while using their non-NGER-mandated peers as potential controls.

Second, we rely on the stock market reaction to the KPR announcement to identify the treated and control firms. KPR could be a bad news for heavy emitters, possibly due to its detrimental effects on firm operating performance and financing costs or a restriction of carbon-intensive activities, whereas it is not necessarily a bad news for light emitters (to some extent, light emitter may even be better off due to reduced competition or better access to external funds following the KPR). Therefore, treated (control) firms include those that experience negative (non-negative) abnormal stock returns around the KPR announcement. In this and the preceding NGER-based tests, we use the propensity score matching (PSM) procedure to select control firms to ensure that each pair of treated and control firms belong to the same industry and are similar along several observable dimensions immediately before the KPR. Our

[2] Source: http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Browse_by_Topic/ClimateChangeold/governance/international/theKyoto. Last accessed on November 4, 2018.

analysis based on firm-level carbon emissions yields results consistent with those based on industry-level carbon emissions.

We run several additional tests to verify the robustness of our findings. First, the treated and control firms' financial leverage could follow different trends even before the KPR and the relation between leverage and KPR could be a spurious one. To alleviate this concern, we estimate the DID dynamic model and the test results indicate that treated firms decrease their leverage after the KPR but not before that. This evidence suggests that the pre-treatment parallel trend assumption underlying the DID model is satisfied. Second, our sample period includes the global financial crisis (GFC) that might affect corporate policies in several ways and confound our findings. In addition, unobservable industry-year factors may also explain our results. We address these concerns by explicitly controlling for the GFC in the baseline regressions and conducting out-of-sample tests using Canadian and U.S. data. We note that Canada also ratified the Kyoto Protocol in 2002, whereas the U.S. has never done so. The test results indicate that our findings are robust. Finally, we rerun the financial leverage regressions using alternative measures of financial leverage to rule out a possibility that treated firms change the composition of debt rather than the total debt levels around the KPR. Our finding continues to hold.

We then investigate the effects of carbon risk on capital structure of firms conditional on their degrees of financial constraints. Intuitively, if the decrease in financial leverage is attributable to an increase in carbon risk, this effect should be stronger for financially constrained firms since these firms face more difficulties when accessing external capital markets (Agrawal and Matsa (2013)) and carbon risk is likely to exacerbate their financial constraints. The lack of external financing may push these firms to reduce investment in carbon risk management and/or discourage them from switching to carbon-efficient technologies. Consistent with this view, we find that the decrease in financial leverage post-KPR is more pronounced for financially constrained heavy emitters as characterized by their small size, dividend omissions, low operating cash flows, or high financial constraint index values, such as the size-age index (Hadlock and Pierce (2010)) and Whited-Wu index (Whited and Wu (2006)).

Next, we show that financial distress risk is a channel through which carbon risk affects capital structure. We employ the modified Altman *Z*-score, earnings volatility, and idiosyncratic volatility as alternative proxies for financial distress risk. The lower the Altman Z-score, the more likely a firm becomes insolvent and the less likely it can repay its debt (MacKie-Mason (1990), Agrawal and Matsa (2013)). Higher earnings and idiosyncratic volatilities imply higher fixed costs that make a firm's cash flows more sensitive to economic downturns and weakens its ability to meet debt payment obligations (Dhaliwal et al. (2016), Serfling (2016)). Our test results indicate that KPR leads to a decrease in Altman Z-score and an increase in earnings and idiosyncratic volatilities for heavy emitters, implying an increase in financial distress risk. In a complementary analysis, we find that the decrease in financial leverage is more pronounced for heavy emitters with higher financial distress risk. Taken together, our evidence indicates that financial distress is a channel through which carbon risk affects firm capital structure.

Our research adds to the literature in two important ways. First, previous studies investigate the relations between macro-economic conditions, institutional features, and firm characteristics and firm financial leverage (e.g., Titman and Wessels (1988), Rajan and Zingales (1995), Korajczyk and Levy (2003), Bancel and Mittoo (2004), Lemmon et al. (2008), Frank and Goyal (2009), Almazan et al. (2010), Agrawal and Matsa (2013)). To the best of our knowledge, our study is the first that establishes a direct relation between carbon risk and firm capital structure. We document that firms that are exposed to higher carbon risk due to more stringent carbon controls decrease financial leverage, and the effect of carbon risk on capital structure works largely through the traditional trade-off mechanism. Thus, our study suggests carbon risk as another important determinant of firm capital structure.

It is noteworthy that some research close to ours mostly focuses on the effects of corporate social responsibilities or environmental responsibilities on the costs of capital (Sharfman and Fernando (2008), El Ghoul et al. (2011), Goss and Roberts (2011), Chava (2014)). While environmental risk can increase both the cost of equity and the cost of debt (Chava (2014)), its net effect on firm capital structure is unclear *ex ante*. Moreover, the relation between firms' environmental responsibilities and the costs of capital is prone to endogeneity concern. For example, Ginglinger and Moreau (2019) report that firm-specific climate risk is negatively related to debt financing. Delis et al. (2019) document that borrowing firms' fossil fuel reserves are positively related to the interest rates that banks charge. However, Shive and Forster (2019) report that access to public equity markets affects greenhouse gas emissions. Kim and Xu (2018) and Levine et al. (2018) find that financial constraints and credit supply shocks affect toxic chemical and waste release. This evidence indicates possible endogeneity of carbon emissions or other environmental variables at firm level due to reverse causality or omitted variable bias, which highlights the need for exogenous measures of carbon risk. Our identification strategy that exploits the Australia's KPR as a plausibly quasi-natural experiment allows us to draw a causal inference about the relation between carbon risk and corporate financing policy.[3]

Second, we add to a growing stream of literature that examines the economic consequences of climate change risks. Matsumura et al. (2013) find that higher carbon emissions are associated with lower firm values. Dessaint and Matray (2017) study the effects of hurricane strikes on managers' perceptions of risk and firm cash holdings. Similarly, Rehse et al. (2019) examine the Hurricane Sandy-induced landfall on the affected firms' market liquidity. Investigating global warming effects, Bernstein et al. (2019) document the influence of the sea level rise on long-run risk and property prices, whereas Choi et al. (2020) study the impact of abnormally warm weather on stock returns. Our study is different in that we focus on the risks arising from the changes in environmental regulations rather than the effects of the changes in physical climate parameters.[4]

The remainder of the paper proceeds as follows. We review the literature and develop testable hypotheses in Section 2. Section 3 discusses carbon risk measure and identification strategy. Section 4 describes data and empirical methodology. Section 5 presents the

[3] Balachandran and Nguyen (2018) also exploit the KPR event as an exogenous shock to carbon risk to examine its effect on firm dividend policy.

[4] Climate-change risk involves risks driven by changes in regulations, changes in physical climate parameters, and changes in other climate-related developments (Matsumura et al. (2013)). Carbon risk is more related to climate-change policies (Aldy and Gianfrate (2019)).

analysis results and discussions. Section 6 concludes the paper.

2. Related literature and hypothesis development

The relation between carbon risk and capital structure is unclear *ex ante*. To the extent that KPR heightens firms' carbon risk, it may discourage them from engaging in carbon-intensive activities while encouraging them to voluntarily switch to cleaner technologies (Dionne and Spaeter (2003)). Accordingly, a transition from a higher to a lower carbon emission state could facilitate a firm's access to external capital markets, potentially leading to an increase in debt financing, hence financial leverage, to exploit interest tax shields (Sharfman and Fernando (2008)).

Notwithstanding the above argument, higher carbon costs can increase firms' financial distress risk, potentially lowering their optimal level of financial leverage. Carbon-intensive firms typically have large fixed costs, which make them vulnerable to changing carbon control regulations. Large investment requirements for cleaner technologies may exceed the financial capability of these firms, prompting them to stick to obsolete polluting production processes while being slow in making investment in pollutants abatement. Moreover, it could be challenging for the firms operating in carbon-intensive industries, such as metals and mining, chemicals, and paper and forest products, to reduce carbon costs when they need to do so, particularly during economic downturns. This feature makes carbon costs more fixed in nature and increase firm operating leverage and financial distress risk. Under the trade-off theory of capital structure, firms choose the mix of debt and equity financing to balance the tax shield benefits and the risk and costs of financial distress associated with debt financing (Kraus and Litzenberger (1973), Scott Jr (1976), Bradley et al. (1984), Graham (2003)). To the extent that carbon risk adversely affects firm performance, thereby decreasing the tax shield benefits while increasing financial distress risk, it will lower their optimal financial leverage. Given the foregoing discussion, we expect the negative effects of carbon risk dominate its positive effects on financial leverage and predict that carbon risk is negatively related to firm financial leverage.

3. Carbon risk measure and identification strategy

In this section, we discuss our measure of carbon risk and identification strategy. We begin by defining heavy and light emitters. We then provide institutional background for the KPR by Australia. Finally, we examine the shareholders' reaction to the KPR announcement to validate our arguments for the exogeneity of the KPR and our classification of heavy (light) emitters as treated (control) firms.

3.1. Definition of heavy and light emitters

We classify firms as either heavy or light emitters based on the emitting nature of their industries. Heavy emitters include firms in the industries recognized as "carbon intensive", which are the biggest GHG emitters or energy consumers. These firms have greater exposure to environmental challenges such as climate change, which may require them to cover carbon-related management and accounting costs, clean-up costs, compliance and litigation costs, or reputation damage (Barth and McNichols (1994), Clarkson et al. (2004), Karpoff et al. (2005)). As carbon control regulations tighten, carbon costs are expected to increase substantially for heavy emitters.

The highest carbon-risk GICS industries include those that reportedly emit the most GHG and consume the most energy as described by the Greenhouse Gas Protocol (GHG Protocol).[5,6] Based on a broad classification, among the 10 GICS *sectors*, three sectors including Energy, Utilities, and Materials emit the biggest amount of GHG. For example, according to AMP Capital, energy, utility, and materials were the largest contributors to ASX200 GHG emission intensity as of the end of August 2015, accounting for 85% of total carbon emissions.[7] Görgen et al. (2020) also find that energy, basic materials, and utilities are the three sectors with the highest carbon risk measured by carbon beta among the 11 sectors studied.

To address a possibility that some industries within these three GICS sectors are less carbon-intensive than others, we further follow the classification of the Carbon Disclosure Project (CDP) to identify the highest emitting GICS *industries* under these three sectors.[8] Accordingly, the following nine industries are reportedly the most carbon-intensive ones (hence defined as heavy emitters) based on the number of million metric tonnes of CO_2e: Oil, Gas and Consumable Fuels; Electric Utilities; Gas Utilities; Independent Power Producers & Energy Traders; Multi-Utilities; Chemicals; Construction Materials; Metals and Mining; and Paper and Forest Products (CDP (2012)).

[5] Global Industry Classification Standard (GICS) is a joint Standard and Poor's and Morgan Stanley Capital International product aimed at standardizing industry definition worldwide (source: http://www.asx.com.au/products/gics.htm).

[6] Source: http://www.ghgprotocol.org/

[7] AMP Capital is a leading Australian investment house with AU$178.9 billion under management as of 30 June 2017. They were among the first to sign on to the Principles for Responsible Investment in 2007 and have broadly considered Environmental, Social and Corporate Governance issues in equity investment strategies and advice (source: https://www.ampcapital.com.au/about-us)

[8] Carbon Disclosure Project (CDP) maintains the global disclosure system that enables corporations, cities, states, and regions to measure and manage their environmental impacts. Its network of investors and purchasers represents US$100 trillion in assets (source: https://www.cdp.net/en/info/about-us). Some recent studies use the environmental information provided by the CDP (e.g., Matsumura et al. (2013)).

3.2. Australia's ratification of Kyoto Protocol

Australia's ratification of the Kyoto Protocol provides a useful setting to examine the relation between carbon risk and firm capital structure for several reasons. First, according to the Climate Change Review Update 2011, Australia is the most polluting nation in the Organisation for Economic Co-operation and Development (OECD) group based on GHG emissions per capita (Garnaut (2011)). Second, following the KPR in 2007, Australian policy makers have enacted several new stringent carbon control regulations with which firms have to comply (Ramiah et al. (2013)). Third, Australia is among the countries with the highest awareness of carbon emission responsibilities by all types of market participants including banks, savers, investors, and business managers (Balachandran and Nguyen (2018)).

One noticeable anecdotal evidence is the rejection by Australia's Big 4 banks (CBA and NAB in 2015, ANZ in 2016, and Westpac in 2017) of the loan application for $12.8 billion to develop the Carmichael coal mine by the Indian conglomerate Adani. If developed, the coal mine would be among the world's largest ones, which produces a climate-destroying 60 million tons of coal annually, mostly for export to India (Banktrack (2018)). The Big 4 banks reached this uneasy decision after experiencing intense pressures from the Australian government, environmental activists, scholars, media and other banks' important stakeholders such as depositors. The banks' rejection decision also signals their determination in tightening credits to fossil fuel-related projects such as coal-fired power plants, which had long been their favorite customers.

The ratification of the Kyoto Protocol in December 2007 was the first act of the newly-elected Labor Prime Minister Kevin Rudd (Ramiah et al. (2013)). The ratification also marked a shift in the stringency of the country's carbon control policies and an end to decades of Australia being criticized as a resource-based economy. Indeed, Australia and United States were the only two major industrialized countries that refused to ratify the Kyoto Protocol when it was first introduced in 1997, and Australia had not taken any decisive actions on cutting the national level of emissions prior to the KPR (Rootes (2008), Subramaniam et al. (2015)). By November 2007, it remained unclear if Australia would ratify the Kyoto Protocol and such an important decision hinged on the outcome of the 2007 federal election. Had the Liberal Party of the then Prime Minister John Howard won the election, the Kyoto Protocol might not have been ratified and the Emission Trading Scheme, which does not commit Australia to emission reduction, would have been adopted instead.[9] Furthermore, the KPR would limit the Australia's GHG emission level for the period 2008–2012 to no more than 8% above its 1990 level, reflecting the Rudd government's commitment to join global efforts in protecting the environment as a top priority. The KPR, therefore, came as an exogenous shock to firms in resource-intensive industries, which had long been the main drivers of the Australian economy.

Fig. 1 plots the percentage of annual contribution to the Gross Domestic Product (GDP) by industry in Australia over the sample period 2002–2013. It is worth noting that the industries belonging to the energy, materials, and utility sectors together account for the biggest proportion of the GDP, ranging from 25.7 to 28.9% per year over the sample period. Other key contributors to the GDP include public industries such as public administration and safety, education and training, and health care and social assistance, which collectively represent approximately 16.7% of the GDP. Financial and real estate industries contribute about 11.1%, wholesale and retail trade industries generate 10.0%, and agriculture and transportation industries contribute around 8.0% of the GDP.

Fig. 2 illustrates the annual carbon dioxide (CO_2) emissions in metric tons per capita by Australia, along with its annual percentage change over the 2002–2013 sample period. The graph displays two noticeable trends. First, in the pre-KPR period, the amount of GHG emissions in Australia increased on average from 17.4 metric tons in 2002 to 17.9 metric tons in 2007. Second, the pace of the increase started to slow down significantly in 2009. These changes result in the level of emissions per capita of 16.3 metric tons in Australia in 2013, which is lower than that in 2002 of 17.4 metric tons, or a 6.7% decrease.[10]

3.3. Market reaction to Australia's ratification of Kyoto Protocol

One may argue that firms could anticipate the KPR or the election of the-then Prime Minister Kevin Rudd that led to the KPR in 2007, which raises concern about the exogeneity of the KPR. In this section, we validate our choice of the KPR as a plausibly exogenous shock to firms' carbon risk by examining the stock market reaction to the announcement of the KPR. We estimate the abnormal stock returns for firms listed on the Australia Stock Exchange (ASX) on December 4, 2007, by taking the difference between the actual and the expected stock returns, where the latter is calculated using the market model parameters estimated over the 200-day window (-260, -61) relative to the announcement day. Given that KPR announcement is a single event date, which may cause substantial cross-sectional correlations in CARs and standard errors, we follow the event study methodology of Kolari and Pynnonen (2010) and adjust the standard errors for event-day clustering.

The decision of the Rudd government on KPR was first announced at late night of December 3, 2007, when the market had already been closed.[11] Thus, we gauge the market reaction over two event windows, two-day CAR(-1,0) and three-day CAR(-1,1),

[9] See the former Prime Minister John Howard's address on June 3, 2007 to the Liberal Party Federal Council (source: http://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22media%2Fpressrel%2FIU9N6%22).

[10] In the 2017 Review of Climate Change Policies report, Australia government confirms that the target of limiting emissions to 108% of the 1990 levels over the 2008–2012 commitment period of KPR was met. More specifically, emissions per capita have declined by 34.2% by March 2017, while the emissions intensity of the whole economy has decreased by 58.4% since 1990 Australia Government (2017).

[11] The news was first released after 5.00 pm on December 3, 2007 by the most popular newspapers in Australia such as ABC News (source: http://www.abc.net.au/news/2007-12-03/rudd-signs-kyoto-ratification-document/976234), or The Age (Source: http://www.theage.com.au/news/

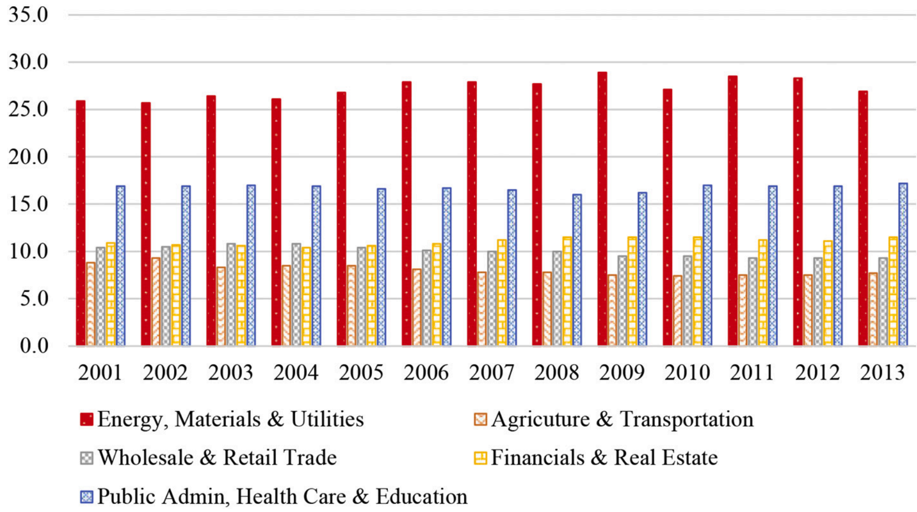

Fig. 1. Percentage of Gross Domestic Product by Industry in Australia.
Source: Australia Bureau of Statistics category no. 5204.0, Table 5

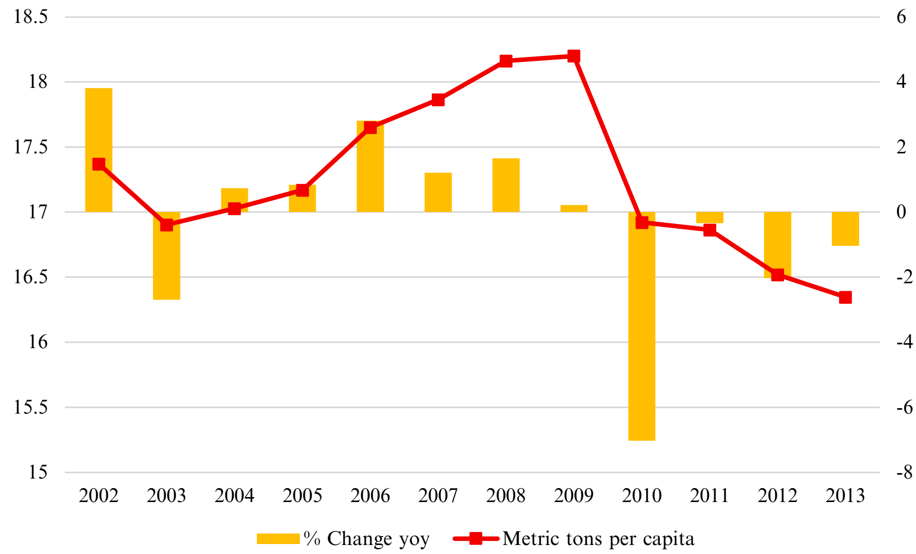

Fig. 2. CO2 Emissions (Metric Tons per Capita) in Australia.
Source: World Bank development indicators.

to account for the possibility that the news was leaked and investor reaction was delayed. We choose to focus on the short event windows to capture the immediate market response to the news (given the relatively high efficiency of the Australian stock markets) while minimizing potential confounding effects of other events.[12]

The results reported in Table 1 indicate that the market reacted negatively to the announcement of KPR by Australia (mean CAR (−1, 0) and CAR(−1, 1) = −0.396% and − 0.360% with *t*-stat. = −2.80 and − 2.16, respectively). Moreover, the negative stock price reaction to the KPR is statistically significant for heavy emitters (CAR(−1, 0) = −0.668% with *t*-stat. = −2.65, and CAR(−1, 1) = −0.534% with *t*-stat. = −1.79) but insignificant for light emitters. These results suggest that the KPR was at least partly unanticipated and had negative (little) effect on the stock prices of heavy (light) emitters. This evidence is consistent with our argument that heavy emitters are vulnerable to higher carbon risk when carbon regulations are tightened.

(*footnote continued*)
national/rudd-ratifies-kyoto/2007/12/03/1196530553722.html).

[12] Longer CAR windows around KPR also indicate significantly different market reactions between heavy and light emitters.

Table 1
Stock Price Reaction to Australia's Ratification of Kyoto Protocol.

	N	CAR(−1,0)		CAR(−1,1)	
		Mean (%)	t-stat.	Mean (%)	t-stat.
Overall	1404	−0.396	−2.80***	−0.360	−2.16**
Heavy Emitters	599	−0.668	−2.65***	−0.534	−1.79*
Light Emitters	805	−0.194	−1.20	−0.231	−1.22

This table displays cumulative abnormal stock returns (CARs) by heavy and light emitters around Australia Government's announcement that the country was going to officially ratify Kyoto Protocol. A firm's CAR is calculated as the difference between the actual and expected returns using the market model parameters estimated over the window (−260, −61) relative to the announcement date. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

4. Data and empirical models

4.1. Data

Our sample consists of 15,484 firm-year observations of 2092 unique firms that were publicly listed in the ASX from 2002 to 2013. We obtain financial data and GICS industry classifications from Morningstar DatAnalysis and stock return data from Datastream. We exclude firms in the financial industries from the sample since these firms may adopt fundamentally different capital structure choices in comparison with others (Diamond and Rajan (2000), DeAngelo and Stulz (2015)). We require a firm-year observation to have non-missing data for the main variables to be included in the sample. The sample period covers the pre-KPR 2002–2007 and the post-KPR 2008–2013 subperiods. The post-KPR subperiod is selected to correspond to the Australian government's commitment period as a part of the KPR and the pre-KPR subperiod is designed to have the same length as the post-KPR subperiod. Note that the original Kyoto Protocol commitment period for Australia is 2008–2012. We extend the sample to include 2013 since a firm's financial leverage in 2013 may reflect its financing choices in 2012. However, our results are qualitatively similar if we restrict the post-Kyoto period to 2008–2012. For the variables that require longer period for calculation such as earnings volatility, we extend the sample period to begin in 2000 and end in 2015.

We use two main measures of financial leverage, book leverage and market leverage, in our analysis. Book leverage (*TDebt/BA*) is the ratio of the sum of short-term and long-term debt to the book value of assets. Market leverage (*TDebt/MA*) is the ratio of the sum of short-term and long-term debt to the market value of assets, where the market value of assets is calculated as the book value of assets minus the book value of equity plus the market value of equity. Control variables consist of firm characteristics that are documented to have power to explain firm capital structure, which include size (*Log(BA)*), growth opportunities (*MB/BA*), profitability (*EBIT/BA*), and tangibility (*PP&E/BA*) (Rajan and Zingales (1995), Leary and Roberts (2014), Simintzi et al. (2014), Graham et al. (2015)). To minimize the impacts of outliers, we winsorize all continuous variables at the top and bottom 1%. The Appendix provides a detailed description of the variables.

Table 2 provides the summary statistics of the main variables. The statistics reported in Panel A indicate that, on average, firms' book and market leverage are 0.165 and 0.116, respectively, and several firms do not use any debt financing as indicated by the 25th percentile value of zero. If we replace total debt with total liabilities to calculate financial leverage, the means of these measures are

Table 2
Summary statistics.

	N	Mean	25th Percentile	Median	75th Percentile	Standard Deviation
$TDebt/BA_t$	14,547	0.168	0.000	0.044	0.243	0.316
$TDebt/MA_t$	14,547	0.115	0.000	0.026	0.182	0.165
$TLiability/BA_t$	14,547	0.416	0.100	0.315	0.537	0.597
$TLiability/MA_t$	14,547	0.271	0.055	0.198	0.427	0.249
$STDebt/BA_t$	14,547	0.068	0.000	0.003	0.056	0.181
$STDebt/MA_t$	14,547	0.046	0.000	0.002	0.040	0.102
$LTDebt/BA_t$	14,547	0.087	0.000	0.001	0.132	0.151
$LTDebt/MA_t$	14,547	0.068	0.000	0.001	0.093	0.122
$Borrow/NF_t$	12,783	0.412	0.000	0.191	1.000	0.767
BA (in mil. AUD)$_{t-1}$	14,547	635.652	7.915	27.588	146.048	2693.864
$EBIT/BA_{t-1}$	14,547	−0.239	−0.270	−0.049	0.077	0.738
$PP\&E/BA_{t-1}$	14,547	0.193	0.016	0.084	0.320	0.227
MA/BA_{t-1}	14,547	2.279	0.931	1.401	2.388	3.182

The sample consists of 14,547 firm-year observations over the period 2002–2013. *TDebt* is total debts, *TLiability* is total liabilities, *STDebt* and *LTDebt* are short and long-term debts, respectively. *BA* and *MA* are book and market values of total assets, respectively. *Borrow* is net borrowing cash flow that equals the proceeds from borrowings net of debt repayment. *NF* is net external financing cash flow that is the sum of net borrowings and equity issues using data from cash-flow statements. *EBIT* is earnings before interest and taxes. *PP&E* is net book value of property, plant and equipment. A detailed description of the variable construction is provided in the Appendix. All continuous variables are winsorized at the 1st and 99th percentiles.

0.403 and 0.276, respectively, suggesting that Australian firms also use other sources of financing such as trade credits or accruals extensively. The ratios of short-term and long-term debt to the book value of assets (market value of assets) are 0.067 and 0.087 (0.047 and 0.068), respectively. In addition, the average cash flow-based borrow ratio (i.e., net borrowing-to-external financing cash flows) is 0.408.

4.2. Difference-in-differences model specification

Our baseline DID model has the following form:

$$LEV_{it} = \beta_0 + \beta_1\, Emitter_i * Post_t + \beta_2\, Emitter_i + \beta_3\, Post_t + \beta_4\, Log(BA)_{it-1} + \beta_5\, EBIT/BA_{it-1} + \beta_6\, PP\&E/BA_{it-1} + \beta_7\, MA/BA_{it-1} + \text{Firm fixed effects} + \text{Year fixed effects} + e_{it} \tag{1}$$

where LEV_{it} is the measure of financial leverage of firm *i* in year *t*. $Emitter_i$ is an indicator that takes the value of one if firm *i* is a heavy emitter, and zero otherwise. $Post_t$ is an indicator that takes the value of one if year *t* is in the post-KPR period, and zero otherwise. The control variables are lagged by one period to alleviate a concern that they are endogenously related to financial leverage. The description of the control variables is provided in the Appendix. The models are estimated with heteroscedasticity-robust standard errors clustered by firms.

The coefficient of interest in Eq. 1 is β_1, which captures the change in financial leverage of heavy emitters relative to that of light emitters from before to after the KPR. A negative β_1 indicates that heavy emitters decrease their leverage relative to that of the light emitters following the KPR, which supports our hypothesis. Since firm fixed effects are an important determinant of leverage ratios (Lemmon et al. (2008)), we control for firm fixed effects in the main specifications. Including firm fixed effects helps to capture within-firm effect and control for potential pre-treatment firm-level differences between treated and control firms (Wooldridge (2012)). We further include year fixed effects to control for time-varying macro-economic conditions that may affect financial leverage (e.g., Cook and Tang (2010)). However, in the models that control for firm and year fixed effects, we do not include the stand-alone $Emitter_i$ and $Post_t$ dummies because their explanatory powers are absorbed by these fixed effects. To address a possible endogenous controls problem (i.e., the "bad control" problem suggested by Roberts and Whited (2013) and Angrist and Pischke (2008)), we follow Serfling (2016) and Klasa et al. (2018) and estimate Eq. 1 without and with time-varying firm-level control variables.

5. Empirical results and discussions

5.1. Univariate analysis

We perform two-sample *t*-tests of the differences in the means of the measures of financial leverage between heavy and light emitters in the pre- and post-KPR periods. We also examine the *changes* in leverage for heavy emitters and light emitters following the Australia's KPR in December 2007.

Table 3 reports the univariate analysis results for the book leverage *TDebt/BA* and market leverage *TDebt/MA* in Panels A and B, respectively. We observe opposite trends in financial leverage of heavy emitters and light emitters following the KPR. Specifically, the results reported in Panel A indicate that heavy emitters decrease their book leverage by 2.6%. In contrast, light emitters increase their book leverage by 2.6%. As a result, the gap in book leverage between these two groups widens to 5.2% (*t*-stat. = 5.37), representing a significant increase from that in the pre-KPR period. We observe a similar pattern for market leverage, which decreases by 0.9% for heavy emitters but increases by 2.4% for light emitters post KPR. In short, the univariate analysis results provide initial evidence of a

Table 3
Univariate analysis.

	Heavy Emitter (HE)		Light Emitter (LE)		*t*-test (HE-LE)	
	Mean	S.D.	Mean	S.D.	Mean diff.	*t*-stat.
Panel A: TDebt/BA						
Pre-Kyoto	0.141	0.314	0.197	0.268	−0.056	−7.77***
Post-Kyoto	0.114	0.308	0.222	0.354	−0.108	−14.59***
Mean diff. (Post-Pre)	−0.026		0.026		−0.052	−4.97***
t-stat.	−3.53***		3.51***			
Panel B: TDebt/MA						
Pre-Kyoto	0.084	0.149	0.137	0.159	−0.053	−13.69***
Post-Kyoto	0.076	0.152	0.161	0.179	−0.085	−23.03***
Mean Diff. (Post-Pre)	−0.009		0.024		−0.032	−6.03***
t-stat.	−2.37**		6.05***			

This table presents the mean, standard deviation, and results of the *t*-tests of mean difference in book leverage (*TDebt/BA*) and market leverage (*TDebt/MA*) between heavy emitters and light emitters in the pre- and post-KPR periods. A detailed description of the variable construction is provided in the Appendix. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 4
Carbon risk and firm financial leverage.

	$TDebt/BA_t$				$TDebt/MA_t$			
	1	2	3	4	5	6	7	8
Emitter*Post	**−0.052*****	**−0.042****	**−0.057*****	**−0.054*****	**−0.032*****	**−0.026*****	**−0.035*****	**−0.041*****
	[−3.46]	[−2.38]	[−4.00]	[−3.02]	[−4.11]	[−3.48]	[−4.76]	[−5.59]
Emitter	−0.056***		−0.049***		−0.053***		−0.041***	
	[−4.70]		[−4.44]		[−7.30]		[−6.31]	
Post	0.026**		0.027***		0.024***		0.025***	
	[2.47]		[2.74]		[4.08]		[4.66]	
$Log(BA)_{t-1}$			0.017***	0.008			0.018***	0.020***
			[7.15]	[1.34]			[11.44]	[9.10]
$EBIT/BA_{t-1}$			−0.059***	−0.044***			−0.015***	−0.010***
			[−6.35]	[−4.20]			[−5.90]	[−4.45]
$PP\&E/BA_{t-1}$			0.250***	0.139***			0.163***	0.087***
			[10.60]	[4.31]			[12.31]	[6.96]
MA/BA_{t-1}			0.009***	0.004*			−0.004***	−0.000
			[2.89]	[1.69]			[−5.51]	[−0.71]
Firm FE	No	Yes	No	Yes	No	Yes	No	Yes
Year FE	No	Yes	No	Yes	No	Yes	No	Yes
Number of observations	14,547	14,547	14,547	14,547	14,547	14,547	14,547	14,547
Adjusted R^2	0.019	0.365	0.090	0.379	0.048	0.587	0.198	0.604

Table reports the results of the difference-in-differences regressions of book and market leverage (*TDebt/BA* and *TDebt/MA*, respectively) on *Emitter*, *Post* dummies, and an interaction term *Emitter*Post*. Some regressions control for size (*Log(BA)*), profitability (*EBIT/BA*), tangibility (*PP&E/BA*), and growth opportunities *(MA/BA)* lagged by one period. Some regression models also control for year and firm fixed effects, but their estimates are suppressed for brevity. The *t*-statistics based on robust standard errors clustered by firms are provided in square brackets. A detailed description of the variable construction is provided in the Appendix. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

negative association between increased carbon risk and firm financial leverage for heavy emitters following the KPR.

5.2. Multivariate analysis

In this section, we examine the effect of the KPR on firm financial leverage in a multivariate setting that controls for other factors that have been documented to affect financial leverage. We estimate Eq. 1 with the dependent variable being either the book leverage (*TDebt/BA*) or market leverage (*TDebt/MA*). Table 4 reports the regression results of the book leverage (Columns 1–4) and market leverage (Columns 5–8). Columns 1 and 5 exclude all control variables and fixed effects. Columns 2 and 6 include both firm and year fixed effects but exclude other control variables. Columns 3 and 7 include control variables but exclude both firm and year fixed effects. Columns 4 and 8 include both control variables and firm and year fixed effects. The results indicate that the coefficients of the interaction term *Emitter*Post* are negative (ranging from −0.052 to −0.026) and statistically significant across all models, suggesting that heavy emitters decrease financial leverage following the KPR. The impact of KPR on the capital structures of heavy emitters is also economically meaningful. For illustration, the coefficient estimates reported in Column 4 (8) of Table 4 indicate that heavy emitters decrease book (market) leverage by 0.054 (0.041), which is equivalent to 17.1% (24.8%) of its standard deviation, following the KPR.[13]

In summary, both the univariate and multivariate results consistently indicate that an increase in carbon risk due to the KPR leads to a decrease in financial leverage of heavy emitters.

5.3. Robustness checks and additional analyses

5.3.1. Test of parallel trend assumption

The DID model is based on the assumption that absent the shock induced by the KPR, the financial leverage of the treated and control firms moves in a similar way (i.e., the pre-treatment parallel assumption). However, if the treatment and control firms are systematically different and their financial leverage moves in different ways even in the absence of the KPR, our results will be invalid. Therefore, we run falsification tests using the dynamic model to validate the pre-treatment parallel trend assumption. Specifically, we create time indicator variables, including KPR^{-3}, KPR^{-2}, KPR^{-1}, KPR^{0}, KPR^{+1}, and KPR^{2+}, which refer to three years before the KPR, two years before the KPR, one year before the KPR, the year of KPR, one year after the KPR, and two or more years after the KPR, respectively, where KPR year is 2008. The coefficients of the interactions between *Emitter* and these indicator variables capture the changes in financial leverage of the treated firms relative to those of the control firms in the corresponding years

[13] Our sample includes a relatively large subset of zero-leverage firms. In a robustness check, we follow Cook and Tang (2010) and exclude zero-leverage firms and re-estimate Equation 1. We find that the sample size drops by about one-third. Moreover, the relative decline in book (market) leverage of the heavy emitters post-KPR is 0.016 (0.026), which is equal to 4.4% (14.7%) of its respective standard deviation.

Table 5
Carbon risk and firm financial leverage – dynamic model.

	$TDebt/BA_t$		$TDebt/MA_t$	
	1	2	3	4
Emitter*KPR^{-3}	**0.002**	**−0.006**	**0.006**	**0.006**
	[0.14]	[−0.38]	[0.75]	[0.86]
Emitter*KPR^{-2}	**−0.009**	**−0.012**	**−0.006**	**−0.005**
	[−0.62]	[−0.73]	[−0.85]	[−0.75]
Emitter*KPR^{-1}	**−0.027**	**−0.026**	**−0.004**	**−0.001**
	[−1.64]	[−1.56]	[−0.48]	[−0.10]
Emitter*KPR^{0}	**−0.033****	**−0.025**	**−0.033******	**−0.032******
	[−1.96]	[−1.49]	[−4.10]	[−4.36]
Emitter*KPR^{+1}	**−0.047******	**−0.044*****	**−0.035******	**−0.036******
	[−2.80]	[−2.54]	[−4.52]	[−4.98]
Emitter*KPR^{2+}	**−0.055******	**−0.047******	**−0.039******	**−0.035******
	[−3.58]	[−3.02]	[−5.54]	[−5.70]
Emitter	−0.066***		−0.050***	
	[−6.10]		[−8.42]	
KPR^{-3}	−0.004		−0.011**	
	[−0.40]		[−2.19]	
KPR^{-2}	−0.000		−0.016***	
	[−0.04]		[−3.17]	
KPR^{-1}	0.008		−0.010**	
	[0.64]		[−1.99]	
KPR^{0}	0.028**		0.033***	
	[2.33]		[5.64]	
KPR^{+1}	0.027**		0.031***	
	[2.28]		[5.34]	
KPR^{2+}	0.017		0.015***	
	[1.45]		[2.84]	
Firm controls	Yes	Yes	Yes	Yes
Firm FE	No	Yes	No	Yes
Year FE	No	Yes	No	Yes
Number of observations	14,547	14,547	14,547	14,547
Adjusted R^2	0.089	0.379	0.199	0.603

The table reports results of the falsification test that counterfactually assumes that the KPR took place a few years before the actual event. The dependent variable is either book leverage or market leverage (*TDebt/BA* or *TDebt/MA*). KPR^{-3}, KPR^{-2}, KPR^{-1}, KPR^{0}, $KPR^{+1}$and KPR^{2+} are indicator variables that indicate three years before the KPR, two years before the KPR, one year before the KPR, the year of KPR, one year after the KPR, and two or more years after the KPR, respectively. All regressions control for size (*Log(BA)*), profitability (*EBIT/BA*), tangibility (*PP&E/BA*), and growth opportunities *(MA/BA)* lagged by one period. Some regression models also control for year and firm fixed effects, but their estimates are suppressed for brevity. The *t*-statistics based on robust standard errors clustered by firms are provided in square brackets. A detailed description of the variable construction is provided in the Appendix. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

relative to the base period 2002–2004. The dynamic model estimation results reported in Table 5 indicate insignificant coefficients of the interaction variables *Emitter*KPR*$^{-3}$, *Emitter*KPR*$^{-2}$, and *Emitter*KPR*$^{-1}$, which suggests that the treated and control firms follow pre-treatment parallel trends in financial leverage.[14]

To demonstrate the trends of financial leverage of the treated and control firms from before to after the KPR graphically, we plot the mean leverage of these two subgroups of firms from five years before to five years after the event year (2008) in Fig. 3. The graphs show parallel trends of financial leverage for the treated and control firms before the actual KPR by Australia but divergent trends after the KPR.[15]

5.3.2. Firm-based definitions of heavy and light emitters

The use of industry-based classification of heavy and light emitters in the above analysis may raise a concern that the *Emitter* dummy variable merely picks up the effect of industry characteristics rather than that of the firm-level exposure to carbon risk. To dispel this concern, we have shown that firms in heavy emitting industries tend to experience negative stock returns around the announcement of the KPR and we control for firm fixed effects in the regression models. Nevertheless, firm-based classifications of heavy and light emitters may better account for the heterogeneity of carbon risk faced by firms. Therefore, we construct two additional emitter dummy variables that arguably capture firm-level exposure to carbon risk from the regulators' and investors'

[14] In a robustness check, we create an indicator variable for each year from 2003 to 2013. The only omitted year is 2002, which serves as the base year. The regression results suggest that the treated firms do not change their leverage significantly within five years before the KPR relative to the base year 2002, and that the decrease in both book and market leverage only shows up from 2008 onwards.

[15] We also consider but do not observe clear trends in median leverage of the two groups.

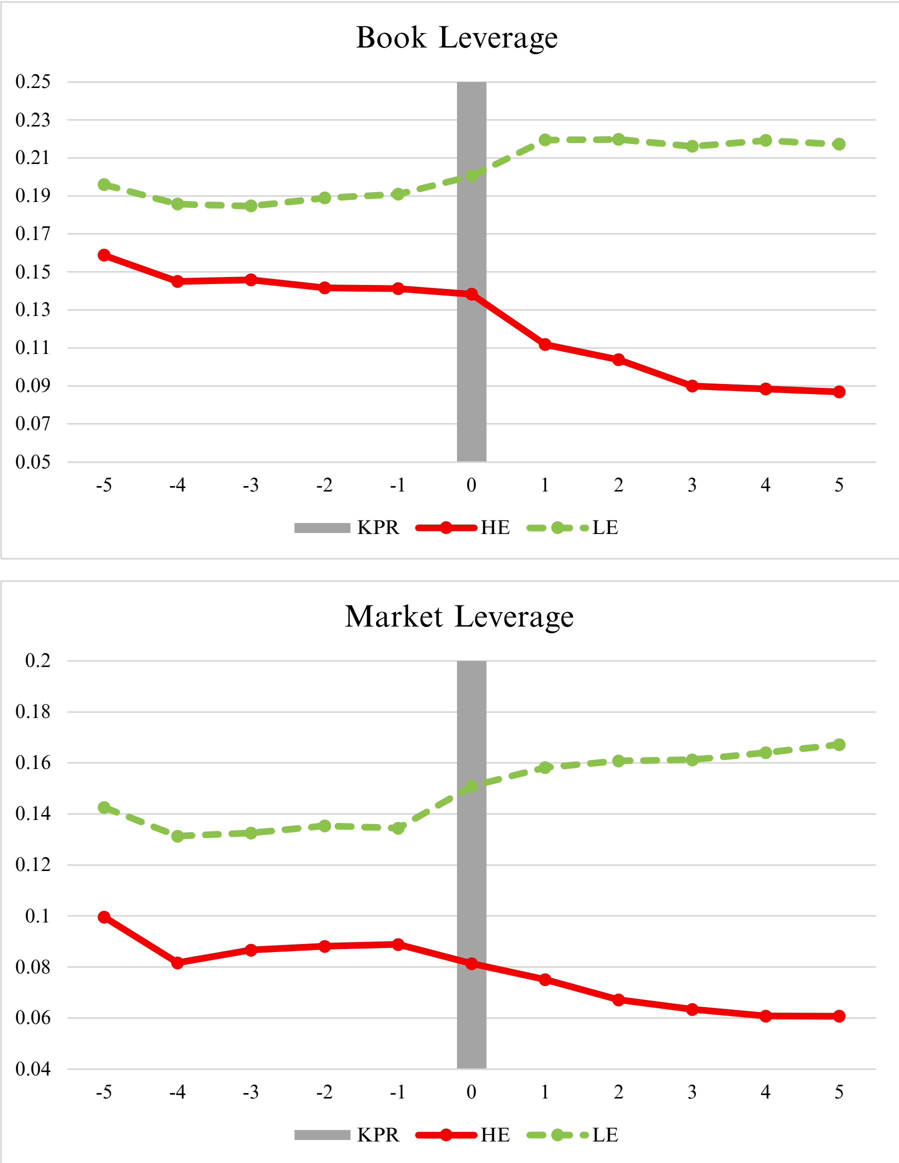

Fig. 3. Time-series Trends in Financial Leverage around the KPR.

perspectives in the next analysis.

5.3.2.1. National Greenhouse and energy reporting act 2007. Our first firm-level measure of carbon risk is based on the introduction of the National Greenhouse and Energy Act (NGER) 2007 that helps gather necessary information for the implementation of KPR in Australia. Specifically, the NGER Act provides a single national legislative framework for the reporting and dissemination of information related to GHG emissions and energy consumption and production of corporations. Under the NGER Act, Australian corporations that emit carbon dioxide and/or consume or produce energy above certain thresholds are mandated to report their greenhouse gas emissions (the six Kyoto gases) and energy production and consumption annually to the Clean Energy Regulator, the government body responsible for administering the Act compliance that subsequently makes the information available to the public. A growing number of businesses has been required to provide their emission and energy consumption information to the government and the public since 2008.[16]

The NGER reporting scheme provides a useful setting for our DID analysis since the NGER-mandated firms are clearly the biggest

[16] Readers can find more details on the NGER Act at the following link: http://www.cleanenergyregulator.gov.au/NGER/About-the-National-Greenhouse-and-Energy-Reporting-scheme.

Table 6
Firm-based definitions of emitters: national greenhouse and energy reporting Act 2007.

Panel A: Post-match Diagnostic Test

	Treated $N = 36$	Control N = 36	Mean Diff.	t-stat.
Log(BA)	18.696	18.665	0.032	0.07
EBIT/BA	−0.005	−0.032	0.027	0.48
PP&E/BA	0.295	0.309	−0.013	−0.23
MA/BA	2.299	2.227	0.071	0.21

Panel B: DID Regression Using PSM-matched Sample

	$TDebt/BA_t$		$TDebt/MA_t$	
	1	2	3	4
Treated*Post	**−0.079***	**−0.090****	**−0.072*****	**−0.069*****
	[−1.93]	[−2.25]	[−2.92]	[−3.56]
Treated	0.033		0.032*	
	[1.16]		[1.88]	
Post	−0.004		0.008	
	[−0.15]		[0.46]	
Firm controls	Yes	Yes	Yes	Yes
Firm FE	No	Yes	No	Yes
Year FE	No	Yes	No	Yes
Number of observations	702	702	702	702
Adjusted R^2	0.098	0.374	0.199	0.613

This table reports the regression results of the impact of carbon risk on book and market leverage using the PSM-matched sample. Panel A presents the post-match diagnostic test results of the *t*-tests of mean differences between treated and control firms. Panel B reports the DID model estimation results using the PSM-matched sample. All regressions control for size (*Log(BA)*), profitability (*EBIT/BA*), tangibility (*PP&E/BA*), and growth opportunities *(MA/BA*) lagged by one period. Some regression models also control for year and firm fixed effects, but their estimates are suppressed for brevity. The *t*-statistics based on robust standard errors clustered by firms are reported in the square brackets. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

emitters that are most likely to be affected by the KPR, whereas non-NGER-mandated peers can be considered light emitters. Following this argument, we define treated firms as those that are required to disclose their emissions and energy information under the NGER Act (hence listed in the Clean Energy Regulator's website) in any reporting year over the period 2008–2013, and possible control firms include the remaining ones. We then follow Megginson et al. (2019) and use the PSM procedure to identify control firms in the same GICS industry and with characteristics similar to those of the treated firms immediately before the KPR. Specifically, in the first stage, we run a probit model of *Treated* dummy on all control variables used in the baseline models and measured in the year preceding the KPR, and obtain the predicted probability of a firm being a treated one. We then match each treated firm with a control firm in the same GICS industry using nearest neighbor matching within 1% caliper. In the second stage, we rerun the DID analysis using the propensity score-matched sample.

Panel A of Table 6 reports results of the *t*-tests for the differences in the means of the observable characteristics of the treated and control firms post match. The test statistics indicate that the PSM procedure produces 36 pairs of treated and control firms that are similar along the observable dimensions.[17] Since we match treated and control firms in the same GICS industry, our analysis is not susceptible to industry effects. Panel B of Table 6 reports the estimation results of the DID models using the propensity score-matched sample. The coefficients of the interaction term *Treated*Post* are all negative and statistically significant, which indicate that treated firms decrease their financial leverage from before to after the KPR.

5.3.2.2. Market reaction to the announcement of KPR. Our second method to identify treated and control firms is grounded on the stock market reaction to the announcement of the KPR as a proxy for the carbon risk exposure of each firm as assessed by investors. A firm is considered to be heavily (lightly) exposed to carbon risk if its investors reacted negatively (non-negatively) to the announcement of KPR. Intuitively, the KPR could be a bad news for carbon-intensive firms since it may increase their operating and financing costs or restrict their carbon emissions. However, the KPR is not necessarily a bad news for low emitting firms since it is not likely to have a significant effect on these firms. To a certain extent, KPR may even reduce competition and facilitate access to external funds for light emitters. Following this proposition, we gauge the stock price reaction to the KPR using the three-day CAR (−1, 1) centered on the KPR day and designate a firm as a treated (control) firm if it experiences negative (non-negative) CAR(−1, 1).[18] Next, we use the PSM procedure to identify control firms based on similar matching criteria as described in the previous test.

[17] There are a few hundred businesses report to the Clean Energy Regulator each year, of which roughly 60% are private companies that we cannot use for analysis since our sample consists of only publicly listed firms.

[18] In an unreported analysis, we employ a two-day CAR(−1,0) instead of three-day CAR(−1,1) for firm classification and obtain qualitatively

Table 7
Firm-based definitions of emitters: stock price reaction to KPR announcement.

Panel A: Post-match Diagnostic Test

	Treated $N = 332$	Control N = 332	Mean Diff.	t-stat.
Log(BA)	17.361	17.481	−0.120	−0.75
EBIT/BA	−0.158	−0.104	−0.055	−1.51
PP&E/BA	0.183	0.174	0.009	−0.52
MA/BA	2.023	2.173	−0.149	1.08

Panel B: DID Regression Using PSM-matched Sample

	$TDebt/BA_t$		$TDebt/MA_t$	
	1	2	3	4
Treated*Post	**−0.029****	**−0.034*****	**−0.017*****	**−0.019******
	[−1.86]	[−2.43]	[−2.12]	[−3.24]
Treated	−0.019*		−0.010*	
	[−1.72]		[−1.76]	
Post	0.023**		0.017***	
	[2.04]		[3.05]	
Firm controls	Yes	Yes	Yes	Yes
Firm FE	No	Yes	No	Yes
Year FE	No	Yes	No	Yes
Number of observations	6296	6296	6296	6296
Adjusted R^2	0.053	0.375	0.113	0.571

This table reports the regression results of the impact of carbon risk on book and market leverage using the PSM-matched sample. Panel A presents the post-match diagnostic test results of the *t*-tests of the mean differences between treated and control firms. Panel B reports the DID model estimation results using the propensity-matched sample. All regressions control for size (*Log(BA)*), profitability (*EBIT/BA*), tangibility (*PP&E/BA*), and growth opportunities *(MA/BA)* lagged by one period. Some regression models also control for year and firm fixed effects, but their estimates are suppressed for brevity. The *t*-statistics based on robust standard errors clustered by firms are reported in square brackets. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The *t*-test statistics reported in Panel A of Table 7 indicate that there are 332 pairs of treated and control firms and they are not significantly different along the observable dimensions post matching, suggesting the success of the matching procedure. We run regressions with model specifications and variables similar to those in Table 6 and report results in Panel B of Table 7. We find consistent evidence that treated firms decrease their financial leverage following the KPR.

In summary, the results of the analysis that uses the firm-based classifications of heavy and light emitters from the regulators' and market's perspectives support the argument that an increase in carbon risk induced by the KPR has a negative effect on firm financial leverage.

5.3.3. *Controlling for the global financial crisis*

Since our sample period includes the global financial crisis (GFC), which coincided with the KPR by Australia, we conduct three tests to alleviate concerns about its possible confounding effects. First, we account for the impact of the GFC on Australian firms' financial leverage by either excluding the GFC years (2008–2009) from the sample period or using the full sample period for analysis but explicitly controlling for the GFC in the regressions. The results reported in Panel A of Table 8 indicate that our findings are robust to controlling for the GFC.

Next, we perform an out-of-sample test using Canada data. We select Canada for this analysis since Canada's economy had also been reliant on carbon-intensive sectors for growth. In addition, Canada ratified the Kyoto Protocol in 2002, which was long before the GFC. The Canadian sample spans the period 1995–2010 because Canada withdrew from the Kyoto Protocol in 2011. For Canada, the *Post* variable takes a value of one for years 2003 onwards and zero otherwise. The results reported in Panel B of Table 8 indicate that Canadian heavy emitters also reduce financial leverage significantly following the country's KPR.

Finally, we conduct a falsification test using U.S. data and assume counterfactually that the U.S. had also ratified the Kyoto Protocol in 2008. Since the U.S. has never adopted the Kyoto Protocol but was affected by the GFC, this falsification test could alleviate any concern that our findings could be driven by the GFC. The U.S. sample period is from 2002 to 2013 to be consistent with that of Australia. The *Post* variable is the same for Australia and the U.S., which takes a value of one for years 2008 onwards and zero otherwise. The results reported in Panel C of Table 8 indicate little change in financial leverage for U.S. heavy emitters following the pseudo KPR. Taken together, the results suggest that our findings are unlikely to be confounded by the GFC.

(*footnote continued*)
similar results.

Table 8
Controlling for the global financial crisis (GFC).

	$TDebt/BA_t$	$TDebt/MA_t$	$TDebt/BA_t$	$TDebt/MA_t$
	1	2	3	4
Panel A: Australian Data				
Emitter*Post	**−0.051****	**−0.035*****	**−0.055*****	**−0.037*****
	[−2.52]	[−4.10]	[−2.83]	[−4.52]
*Emitter*GFC*			0.004	−0.011
			[0.30]	[−1.57]
Firm controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Number of observations	11,879	11,879	14,547	14,547
Adjusted R^2	0.358	0.590	0.379	0.604
Panel B: Canadian Data				
Emitter*Post	**−0.059*****	**−0.052*****	**−0.061*****	**−0.053*****
	[−2.74]	[−3.45]	[−3.01]	[−3.79]
*Emitter*GFC*			0.014	0.005
			[0.43]	[0.21]
Firm controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Number of observations	5202	5202	5202	5202
Adjusted R^2	0.189	0.301	0.189	0.301
Panel C: U.S. Data				
Emitter*Post	**−0.009**	**−0.005**	**−0.007**	**−0.005**
	[−0.56]	[−1.42]	[−0.42]	[−1.10]
*Emitter*GFC*			−0.003	−0.002
			[−0.25]	[−0.42]
Firm controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Number of observations	83,558	83,558	83,558	83,558
Adjusted R^2	0.604	0.716	0.604	0.716

This table reports the results of the difference-in-differences regressions of book and market leverage (*TDebt/BA* and *TDebt/MA*) on *Emitter*Post* controlling for *Emitter*GFC* using data from Australia, Canada, and United States (in Panels A, B, C, respectively), where *GFC* is a dummy variable indicating the global financial crisis period 2008–2009. The regression models control for size (*Log(BA)*), profitability (*EBIT/BA*), tangibility (*PP&E/BA*), and growth opportunities *(MA/BA)* lagged by one period, and firm and year fixed effects, but their estimates are suppressed for brevity. The *t*-statistics based on robust standard errors clustered by firms are provided in square brackets. A detailed description of the variable construction is provided in the Appendix. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

5.3.4. *Alternative measures of financial leverage*

In this section, we consider alternative measures of financial leverage, which include total liabilities and short-term and long-term debt ratios (Titman and Wessels (1988)). This consideration is important since Rauh and Sufi (2010) point out that "fallen angels" may change the composition of firm debt rather than the total debt levels. We construct six additional proxies for financial leverage for which the relevant data are available, including *TLiability/BA, TLiability/MA, STDebt/BA, STDebt/MA, LTDebt/BA,* and *LTDebt/MA* (Keefe and Yaghoubi (2016)). The summary statistics reported in Table 2 indicate a large variation among these measures. For example, the mean of *TLiability/BA* (0.416) is more than 2.4 times that of *TDebt/BA* (0.168), which suggests that a large portion of an average firm's assets is financed with trade credits and/or accruals in addition to bank borrowings or debt issues.

We further consider another measure of leverage, *Borrow/NF*, which is the cash flow-based borrow ratio (Bradshaw et al. (2006), Butler et al. (2011), Lewis and Tan, 2016). While the two main measures of financial leverage used in the baseline regressions (*TDebt/BA* and *TDebt/MA*) are subject to mean reversion over time, the cash flow-based borrow ratio can better capture the actual financing activities, that is, how much a firm's net financing is raised through debt versus equity issuance. Therefore, this measure is more dynamic and less likely to be driven by time trends (Lemmon et al. (2008)). However, one caveat of the cash flow-based borrow ratio is that it could be a noisy measure, especially when firms raise extremely small or large amounts of debt relative to equity (Lewis and Tan (2016)).

The results reported in Table 9 indicate that the coefficients of the interaction *Emitter*Post* are all negative, ranging from −0.095 to −0.017, and statistically significant across all models with alternative measures of financial leverage as dependent variables. This evidence suggests that heavy emitters reduce not only the aggregate but also the components of debts and other forms of liabilities in their capital structures.

Table 9
Alternative measures of financial leverage.

	$TLiability/BA_t$	$TLiability/MA_t$	$STDebt/BA_t$	$STDebt/MA_t$	$LTDebt/BA_t$	$LTDebt/MA_t$	$Borrow/NF_t$
	1	2	3	4	5	6	7
Emitter*Post	**−0.095******	**−0.075******	**−0.020****	**−0.017*****	**−0.023*****	**−0.017*****	**−0.076****
	[−2.85]	[−7.30]	[−2.11]	[−3.54]	[−3.32]	[−3.54]	[−2.43]
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	14,547	14,547	14,547	14,547	14,547	14,547	12,706
Adjusted R^2	0.343	0.654	0.269	0.379	0.537	0.379	0.174

This table reports the regression results of seven alternative measures of financial leverage including *TLiability/BA*, *TLiability/MA*, *STDebt/BA*, *STDebt/MA*, *LTDebt/BA*, *LTDebt/MA*, and *Borrow/NF* on the interaction term *Emitter*Post*. All regressions control for size (*Log(BA)*), profitability (*EBIT/BA*), tangibility (*PP&E/BA*), and growth opportunities (*MA/BA*) measured lagged by one period. The models control for firm and year fixed effects but their estimates are suppressed for brevity. The *t*-statistics based on robust standard errors clustered by firms are provided in square brackets. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

5.4. Carbon risk and financial constraints

Due to their insufficient internal cash flow and lack of access to external capital markets, financially constrained heavy emitters may find it harder to cover increased carbon costs and invest in new technology that reduces carbon emissions to meet the more stringent carbon control regulations, thus, carbon risk could be more harmful to these firms. Following this proposition, we predict that the negative effect of carbon risk on financial leverage is more pronounced for financially constrained firms. Note that since the relation between carbon risk and market leverage could be driven by the fluctuation in stock prices rather than the change in financing policies (Welch (2004)) and managers typically rely on book leverage to make capital structure decisions (Graham (2003), Serfling (2016)), to save space, we report the book leverage analysis results for discussion from here onwards. However, all of our findings are essentially similar if we use the market leverage as the dependent variable.

To test our prediction, we sort firms into either financially constrained (FC) or unconstrained (UC) subgroup based on firm characteristics including firm size, dividend payouts, and operating cash flows (Agrawal and Matsa (2013)), and FC indices including size-age index (Hadlock and Pierce (2010)), and Whited-Wu index but excludes the financial leverage component (Whited and Wu (2006)). FC firms include those that have book assets below the sample median, zero dividend, operating cash flows-to-total assets ratio below the sample median, and the size-age index or Whited-Wu index above their respective sample medians. The remaining firms are considered financially unconstrained. Consistent with our prediction, the results reported in Table 10 indicate that the coefficients of *Emitter*Post* interaction term are negative and larger in magnitude for FC than for UC firms across all five financial constraint measures.

5.5. Channel of effects: Financial distress risk

Our results thus far suggest that an increase in carbon risk leads to a decrease in financial leverage. In this section, we perform two tests to examine whether financial distress risk is a channel through which carbon risk affects capital structure. In the first test, we examine the direct relation between carbon risk and financial distress. In the second test, we re-examine the relation between carbon risk and firm financial leverage conditional on the level of financial distress. To the extent that carbon risk heightens firms' financial distress risk, leading to reduced leverage, we expect a positive relation between carbon risk and financial distress and a stronger negative relation between carbon risk and financial leverage for firms faced with higher financial distress risk.

We employ three measures of financial distress risk in this analysis. The first measure is modified Altman *Z*-score developed by MacKie-Mason (1990), which indicates the likelihood of bankruptcy of a firm in a given year and is calculated as: Z-score = 3.3**EBIT/BA* + 1.0**Sales/BA* + 1.4**Retained/BA* + 1.2**WCap/BA*, where *EBIT* is earnings before interest and taxes, *Sales* is total revenue, *Retained* is retained earnings, *WCAP* is working capital. A lower Z-score implies a higher likelihood of bankruptcy. The second proxy for financial distress risk is *RoaVol*, which measures a firm's earnings volatility, calculated as the standard deviation of annual *EBIT/BA* over five-year rolling windows. Firms with higher degrees of fixed costs relative to total costs have their earnings more susceptible to changing economic conditions, resulting in higher earnings volatility, hence higher financial distress risk (Lemmon et al. (2008), Serfling (2016)). The third proxy is *IVol*, which is a market-based variable capturing idiosyncratic volatility. This measure is computed as the annualized standard deviation of the residuals from regressing daily individual stock returns on market returns (Dhaliwal et al. (2016)). Since these proxies are highly skewed, we rank Z-score into deciles on yearly basis (*ZS_Dec*) and take the natural logarithm of *RoaVol* and *IVol* before fitting into the regression models (Keefe and Yaghoubi (2016)) (see the Appendix for a detailed description of the variable construction).

Table 11 reports the test results. In Panel A, we re-estimate Eq. 1 with the dependent variable being either *ZS_Dec* (Column 1), *Log (RoaVol)* (Column 2), or *Log(IVol)* (Column 3). The results indicate that heavy emitters experience increases in default probability, earnings volatility, and idiosyncratic volatility in the post-KPR period, suggesting that heavy emitters face higher financial distress risk than light emitters do. In unreported analysis, we find that the results are qualitatively similar if we rank *ZScore* into terciles,

Table 10
The role of financial constraints.

Panel A: Firm Characteristics

	Size		Dividend		Operating Cash-flow	
	FC (< Median)	UC (> Median)	FC (Zero)	UC (Postive)	FC (< Median)	UC (> Median)
	1	2	3	4	5	6
Emitter*Post	**−0.081****	**−0.043*****	**−0.095*****	**−0.034*****	**−0.107*****	**−0.045*****
	[−2.39]	[−3.44]	[−3.42]	[−2.75]	[−3.07]	[−3.84]
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	7170	7149	10,066	4297	6872	6779
Adjusted R^2	0.349	0.660	0.343	0.704	0.366	0.707
Chi-squared test (*p*-value)	2.92 (0.09*)		11.80 (0.00***)		7.64 (0.01***)	

Panel B: FC Indices

	SA Index		WW Index	
	FC (> Median)	UC (< Median)	FC (> Median)	UC (< Median)
	1	2	3	4
Emitter*Post	**−0.044*****	**−0.066**	**−0.158*****	**−0.025**
	[−3.64]	[−1.63]	[−3.90]	[−1.11]
Firm controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Number of observations	6656	6685	5126	5293
Adjusted R^2	0.654	0.343	0.381	0.550
Chi-squared test (*p*-value)	1.02 (0.31)		18.62 (0.00***)	

This table reports the results of the regression of book leverage (*TDebt/BA*) on the interaction term *Emitter*Post* for subsamples of firms sorted on the degree of financial constraints. A firm is defined to be financially constrained (FC) if its i) size (*Log(BA)*) is smaller than the yearly median, ii) dividends (*Div*) are omitted, iii) ratio of operating cash flows to assets (*OCF/BA*) is smaller than the yearly median (in Panel A), or size-age iv) or Whited-Wu index is higher than the yearly median (in Panel B). The remaining firms are defined to be financially unconstrained (UC). All regressions control for size (*Log(BA)*), profitability (*EBIT/BA*), tangibility (*PP&E/BA*), and growth opportunities (*MA/BA*) lagged by one period, and firm and year fixed effects, but their estimates are suppressed for brevity. The *t*-statistics based on robust standard errors clustered by firms are provided in square brackets. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

quartiles, or quintiles.

In Panel B, we re-estimate Eq. 1 with the dependent variable being book leverage, *TDebt/BA*, for subsamples of financially distressed (FD) and undistressed (UD) firms sorted on either Z-score (Columns 1 and 2), *RoaVol* (Columns 3 and 4), or *IVol* (Columns 5 and 6). Since financial distress is an extreme case when firms are close to bankruptcy, we define FD firms as those belonging to the first quartile of the sample Z-score (fourth quartile of sample *RoaVol* or *IVol*) and define UD firms as those belonging to the fourth quartile of sample Z-score (first quartile of sample *RoaVol* or *IVol*) on an annual basis. The estimation results indicate that the decrease in book leverage of heavy emitters is more pronounced for FD firms compared to UD firms. For example, the results in Columns 1 and 2 suggest that FD heavy emitters decrease their book leverage significantly from before to after the KPR while UD heavy emitters experience little change in leverage relative to the control light emitters. Overall, our evidence is consistent with the view that carbon risk heightens financial distress risk, motivating firms to lower financial leverage.

5.6. Carbon risk and corporate investments

New stringent environmental policies following the KPR may render carbon-intensive investment projects of the heavy emitters unfeasible, motivating them to reduce investment. In this section, we examine an alternative explanation that a decrease in investment, rather than an increase in financial distress risk, induced by carbon risk leads to a decrease in debt financing. Specifically, we run a DID regression of investment on *Emitter*, *Post*, their interaction *Emitter*Post*, and other control variables. The investment model specification is similar to Fazzari et al. (1988) and Peters and Taylor (2017). Investment is measured as capital expenditures in year *t* scaled by the book value of assets at the beginning of the year, $Capex_t/BA_{t-1}$ (the results are qualitatively unchanged if we scale

Table 11
Channel analysis: financial distress risk.

Panel A: Carbon Risk and Financial Distress Risk

	ZS_Dec_t	$Log(RoaVol)_t$	$Log(IVol)_t$
	1	2	3
Emitter*Post	**−0.022*****	**0.099****	**0.132*****
	[−3.06]	[2.56]	[2.67]
Firm controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Number of observations	14,547	14,547	11,380
Adjusted R^2	0.662	0.700	0.300

Panel B: Carbon Risk, Financial Distress, and Financial Leverage

	$TDebt/BA_t$		$TDebt/BA_t$		$TDebt/BA_t$	
	FD (Q1 *ZScore*)	UD (Q4 *ZScore*)	FD (Q4 *RoaVol*)	UD (Q1 *RoaVol*)	FD (Q4 *IVol*)	UD (Q1 *IVol*)
	1	2	3	4	5	6
Emitter*Post	**−0.139****	**−0.032***	**−0.224*****	**−0.018**	**−0.123****	**−0.040*****
	[−2.27]	[−1.84]	[−3.61]	[−1.60]	[−2.08]	[−2.64]
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	3339	3393	3532	3445	2548	2723
Adjusted R^2	0.387	0.670	0.305	0.821	0.444	0.794
Chi-squared test (*p*-value)	6.40 (0.01***)		23.17 (0.00***)		4.35 (0.04**)	

The table reports results of the direct and indirect tests on financial distress risk channel. Panel A presents regression results of financial distress risk measure (*ZS_Dec*, *Log(RoaVol)*, or *Log(IVol)*) on the interaction term *Emitter*Post*. Panel B reports regression results of book leverage (*TDebt/BA*) on the interaction term *Emitter*Post* for subsamples of firms sorted on the degree of financial distress. Firms with *Z*-score (*RoaVol* and *IVol*) below (above) 25th (75th) percentile value are defined to be financially distressed (FD). Firms with Z-score (*RoaVol* and *IVol*) above (below) 75th (25th) percentile values are defined to be financially undistressed (UD). Firms are ranked on yearly basis of their financial distress condition. All regressions control for size (*Log(BA)*), profitability (*EBIT/BA*), tangibility (*PP&E/BA*), and growth opportunities (*MA/BA*) lagged by one period, and firm and year fixed effects, but their estimates are suppressed for brevity. The *t*-statistics based on robust standard errors clustered by firms are provided in square brackets. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

capital expenditure by lagged property, plant, and equipment (PPE_{t-1})). We control for firm growth opportunities, proxied by Tobin's Q, at the beginning of the year (MA_{t-1}/BA_{t-1}), and contemporaneous cash flows scaled by the book value of assets at the beginning of the year (CF_t/BA_{t-1}). Table 12 reports the investment regression results. The coefficients on the interaction term *Emitter*Post* in Columns 1 and 2 are statistically insignificant, suggesting that heavy emitters do not change the level of investments significantly relative to that of light emitters following the KPR. This evidence rules out the possibility that carbon risk has only second order effect on firm financial leverage through investment.

5.7. Additional robustness checks

We conduct a battery of robustness checks and summarize the findings in this section (for brevity, we report the results in the Internet Appendix).

First, we adopt alternative definitions of treated and control firms that are industry- or firm-based. With regard to the industry-based identification, we use three additional definitions by: i) including transportation industries into the heavy emitter group, ii) classifying firms in industries with top six stranded assets (Krueger et al. (2020)), or iii) assigning the top three climate risk sectors (Andersson et al. (2016)) into the heavy emitter group. With regard to the firm-based identification, we check the sensitivity of the two main tests: i) for NGER-based test, we adopt three alternative looser calipers of 2%, 3%, and 5%, or ii) for CAR-based test, we employ stricter criteria of CARs being less than −0.5%, −1%, and − 1.5% to define treated firms. The test results reported in Tables IA1, IA2, and IA3 in the Internet Appendix indicate the robustness of our main findings.

Second, we check the robustness of our main results to winsorizing data at the 2%, 3%, or 5% levels, and excluding firm-year observations with leverage ratio greater than one. The results reported in Table IA4 in the Internet Appendix indicate that our findings continue to hold.

Third, we conduct additional tests to rule out other possible explanations for our results. We consider the possibility that firm-level information asymmetry increases following the KPR due to an increase in investment to meet more stringent emission standards, motivating the treated firms to use internal and debt rather than equity financing. We use Amihud's (2002) illiquidity measure as a

Table 12
Carbon risk and firm capital investment.

	$Capex_t/BA_{t-1}$	
	1	2
Emitter*Post	**−0.005**	**0.014**
	[−0.58]	[1.38]
Emitter	0.030***	
	[3.99]	
Post	−0.014***	
	[−3.03]	
MA_{t-1}/BA_{t-1}	0.002**	0.006***
	[2.03]	[4.17]
CF_t/BA_{t-1}	0.085***	0.069***
	[9.61]	[7.88]
Firm FE	No	Yes
Year FE	No	Yes
Number of observations	14,100	14,078
Adjusted R^2	0.040	0.114

This table reports the results of the regressions of investment ($Capex_t/BA_{t-1}$) on *Emitter*, *Post* dummies, and an interaction term *Emitter*Post*. All regressions control for growth opportunities (MA_{t-1}/BA_{t-1}), and cash flow (CF_t/BA_{t-1}). The regressions also control for year and firm fixed effects, but their estimates are suppressed for brevity. A detailed description of the variable construction is provided in the Appendix. The *t*-statistics based on robust standard errors clustered by firms are provided in square brackets. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

proxy for firms' information asymmetry and run regression of this measure on carbon risk variables and other controls. The results reported in Columns 1 and 2 of Table IA5 in the Internet Appendix indicate insignificant coefficients of *Emitter*Post*, suggesting little change in the level of information asymmetry for the treated firms relative to that of the control firms following the KPR. In addition, we follow Shyam-Sunder and Myers (1999) and Bharath et al. (2009) to examine the relation between carbon risk and net debt issue conditional on financing deficit (*DEF*), which is calculated as the sum of dividend payments, capital expenditures, and net change in working capital, minus operating cash flow. Specifically, we regress the net debt issue (Δ*Debt*) on the three-way interaction *Emitter*Post*DEF* variable and other controls. Following the pecking order theory, if an increase in information asymmetry following the KPR drives our results, we expect the effect of financing deficit on debt financing to be positive (i.e., debt is preferred to equity) and stronger for the treated firms after the KPR. The results reported in Columns 3 and 4 of Table IA5 indicate that the coefficients on the three-way interaction *Emitter*Post*DEF* are negative and significant, which is inconsistent with the information asymmetry argument.

Another possible explanation for our results is firms' environmental, social and governance (ESG) commitment. Previous studies document that firms' environmental efforts help reduce their financing costs, thus, the carbon reduction efforts might make equity financing a more appealing choice to firms from the cost perspective (e.g., Sharfman and Fernando (2008), Chava (2014)). To test the ESG channel, we examine whether the reduction in financial leverage is due to a decrease in debt financing, an increase in equity financing, or both. We construct two cash flow-based metrics: i) *Net Debt Ratio*, which is computed as *Net Debt* (i.e., borrowing proceeds minus repayments) scaled by *Net External Financing* (*NEF*), and ii) *Equity Ratio*, which is computed as *Equity Issue* (i.e., net proceeds of equity issue) scaled by *NEF*, to capture the actual financing activities. *NEF* is the sum of *Net Debt* and *Equity Issue*. In a complementary analysis, we use *Debt* instead of *Net Debt* and hence *External Financing* (or *EF*) instead of *NEF*. The regression results reported in Table IA6 in the Internet Appendix indicate that debt financing decreases while equity financing increases for the treated firms after the KPR. In an untabulated analysis, we follow Nguyen et al. (2020) and examine the relations between carbon risk and the costs of debt and equity. Consistent with their results, we find that carbon risk is positively related to both the costs of debt and equity. These results rule out a lower cost of equity associated with ESG as a possible explanation for our findings. The evidence also implies that firms have to resort to equity financing although the cost of this source of capital increases following the KPR.

Market timing could be another driver of the corporate financing decision. If firms issue more equity when the stock price is high, then the decrease in financial leverage could be driven by an increase in equity financing rather than a decrease in debt financing. However, we observe negative abnormal stock returns for treated firms around the KPR announcement, indicating a relative decrease in their stock prices. Furthermore, stock prices largely dropped during the GFC, making equity financing a less viable option. To empirically examine whether a change in equity valuation during the GFC leads to a change in the capital structure of treated firms, we run regressions of financial leverage on the *GFC* dummy variable and its interaction with *Emitter* and other controls. The insignificant coefficients of the interaction variable *Emitter*GFC* reported in Panel A of Table 8 indicate that the change in equity valuation during the GFC has little effect on financial leverage, thus, market timing is unlikely a driver of our results. Moreover, our finding of an increase in the cost of equity following the KPR further rules out market timing as an explanation for our results.[19]

Fourth, we conduct additional analysis of the impact of carbon risk on bank loans. We use a hand-collected sample of bank loans

[19] We thank an anonymous reviewer for suggestion to consider alternative explanations for our findings.

in this analysis since bank loans are the main source of debt financing for Australian firms. The results reported in Table IA7 in the Internet Appendix indicate that heavy emitters are less likely to be financed by major banks (i.e., big 4 banks in Australia including ANZ, CBA, Westpac, and NAB) and are more likely to obtain new loans from new lenders (as opposed to refinancing existing loans with the current lenders) following the KPR. This evidence implies that heavy emitters are likely to be screened out by big banks due to their increased carbon risk exposure, therefore, they have to rely on less reputable lenders for their financing needs. Although we cannot rule out the demand side effect on debt financing completely, our results, at the minimum, suggest the dominating effect of the supply side. To the extent that debt financing is not available or costly, heavy emitters have to resort to equity financing as discussed above.

Fifth, we control for additional firm characteristics including tax payment, depreciation and operating expenses all scaled by total assets, and macroeconomic variables including aggregate corporate profit growth and equity market return (note that commercial papers are not developed in Australian markets) (Korajczyk and Levy (2003), Levy and Hennessy (2007)). The results reported in Table IA8 in the Internet Appendix indicate that our findings are qualitatively unchanged.

Finally, we adopt alternative investment measures in our carbon risk and investment analysis. In particular, we use the change in capital expenditure and the change in net investment (Edmans et al. (2017)) to examine whether carbon risk results in an increase in corporate investment of the treated firms. The insignificant coefficients of *Emitter*Post* across regression models reported in Table IA9 in the Internet Appendix are inconsistent with this argument. This evidence further suggests that the decrease in leverage of treated firms is unlikely to be driven by a change in investments. The results of this and previous tests suggest financial distress as the channel through which carbon risk affects firm financial leverage.

6. Conclusion

We exploit the ratification of the Kyoto Protocol by Australia in December 2007 that exogenously increases carbon risk faced by carbon-intensive firms to examine its effects on firm capital structure. We find that relative to the light emitters, heavy emitters decrease financial leverage following the KPR and the decrease is more pronounced for financially constrained heavy emitters. Further analysis indicates that carbon risk results in an increase in firms' financial distress risk, which motivate firms to decrease financial leverage. Our findings highlight carbon risk as an important determinant of firm capital structure and potential adverse effects of stringent environmental policies on corporate financing behavior.

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Appendix A. Definitions of variables

Variable	Definition
Panel A: Carbon risk variables	
Emitter	A dummy variable that indicates if a firm is classified into one the following nine GICS industries: (1) Oil, Gas & Consumable Fuels; (2) Electric Utilities; (3) Gas Utilities; (4) Independent Power Producers & Energy Traders; (5) Multi-Utilities; (6) Chemicals; (7) Construction Materials; (8) Metals & Mining; and (9) Paper & Forest Products
Post	A dummy variable that indicates the post-Kyoto period 2008–2013
Panel B: Scaling variables	
BA	Book value of assets
MA	Market value of assets, which is equal BA - BE + ME, where BE and ME are book and market value of equity, respectively
NF	Net external financing cash-flows, which are equal Borrow + Issue, where Borrow and Issue are net proceeds from borrowing and securities issuing activities
Panel C: Leverage variables	
TDebt/BA	Ratio of total debts to the book value of assets
TDebt/MA	Ratio of total debts to the market value of assets
TLiability/BA	Ratio of total liabilities to the book value of assets
TLiability/MA	Ratio of total liabilities to the market value of assets
STDebt/BA	Ratio of short-term debts to the book value of assets
STDebt/MA	Ratio of short-term debts to the market value of assets
LTDebt/BA	Ratio of long-term debts to the book value of assets
LTDebt/MA	Ratio of long-term debts to the market value of assets
Borrow/NF	Ratio of net proceeds from borrowings to net external financing cash-flows
Panel D: Financial constraint variables	
Div	Dividend paying dummy that indicates if a firm-year pays cash dividend
OCF/BA	Ratio of operating cash-flows to the book value of assets, where OCF is equal after-tax earnings + depreciations

Panel E: Financial distress variables	
Z-score	Modified Altman Z-score, that is equal 3.3*EBIT/BA + 1.0*Sales/BA + 1.4*Retained/BA + 1.2*WCap/BA, where EBIT is earnings before interest and taxes, Sales is total revenue, Retained is retained earnings, WCAP is working capital
ZS_Dec	Z-score deciles, which is *ZScore* ranked into deciles on yearly basis, minus 1, then divided by 10
RoaVol	Earnings volatility, which is equal standard deviation of annual Net Income/BA over 5-year rolling window. We require a minimum of 3 consecutive non-missing observations
IVol	Idiosyncratic volatility, that is equal annualized standard deviation of the residuals from regressing daily individual stock returns on the market returns
Panel F: Firm control variables	
Log(BA)	Logarithm transformation of the book value of assets
EBIT/BA	Ratio of earnings before interest and taxes to the book value of assets
PP&E/BA	Ratio of net property, plant and equipment to the book value of assets
MA/BA	Ratio of market to the book values of assets

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcorpfin.2020.101713.

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