HONG KONG INSTITUTE FOR MONETARY AND FINANCIAL RESEARCH

THE EFFECT OF CARBON PRICING ON FIRM PERFORMANCE: WORLDWIDE EVIDENCE

Tinghua Duan, Frank Weikai Li and Hong Zhang

HKIMR Working Paper No.06/2024

June 2024

HONG KONG ACADEMY OF FINANCE 金融學院

Hong Kong Institute for Monetary and Financial Research
香港貨幣及金融研究中心
(a company incorporated with limited liability)

The Effect of Carbon Pricing on Firm Performance: Worldwide Evidence*

Tinghua Duan   Frank Weikai Li   Hong Zhang†

June 2024

* We thank Ning Gao, Claire Yurong Hong, Onur Boyabatli, Giorgio Valente, Tianhao Yao, and the seminar participants at the University of Manchester, Lancaster University, SAIF, SMU, and the Hong Kong Institute for Monetary and Financial Research for their helpful comments. Frank Weikai Li gratefully acknowledges financial support from the Hong Kong Institute for Monetary and Financial Research. This paper represents the views of the author(s), which are not necessarily the views of the Hong Kong Monetary Authority, the Hong Kong Academy of Finance Limited, or the Hong Kong Institute for Monetary and Financial Research. The above-mentioned entities, except the author(s), take no responsibility for any inaccuracies or omissions contained in the paper.

† Tinghua Duan: IESEG School of Management, Univ. Lille, CNRS, UMR 9221 – LEM – Lille Economie Management, F-59000 Lille, France. Email: t.duan@ieseg.fr. Frank Weikai Li: Lee Kong Chian School of Business, Singapore Management University. Email: wkli@smu.edu.sg. Tel: (65) 6568289651. Hong Zhang: Lee Kong Chian School of Business, Singapore Management University. Email: hongzhang@smu.edu.sg. Tel: (65) 68289086.

Abstract

Economists recommend combating climate change with carbon pricing; however, a major block to pricing emissions is concerns about economic costs. This paper examines the impacts of carbon pricing initiatives on the operating performance and market value of publicly listed firms around the world. Using the staggered enactment of carbon pricing initiatives across jurisdictions and a triple difference approach, we find a significant reduction in the profitability and value of carbon-intensive firms relative to low-emission firms after the enactment of carbon pricing policies. The reduction in firm profits is driven by both a decrease in sales growth and an increase in operating costs. The reduction in firm value is driven by both an increase in the cost of capital and a decrease in expected future cash flows. Carbon-intensive firms also cut investments, lay off employees, and hold more cash. Cross-country analyses show a stronger effect for firms headquartered in North America and in countries that rely more on fossil fuel energy. Overall, our findings uncover the large distributional impacts of carbon pricing policies on individual firms and complement prior studies focusing on the macroeconomic effects of such policies.

JEL Classification: G15, G32, E62, H23

Keywords: Climate change, carbon pricing, carbon tax, emission trading systems, carbon premium, distributional effects

1. Introduction

Climate change, caused mainly by the concentration of greenhouse gases (GHGs) in Earth's atmosphere, is one of the most pressing challenges of this century. Economists widely agree that the most effective way to reduce GHG emissions is to internalise the externality through putting a price on carbon emissions (Stiglitz, 2019; Adrian, Bolton, and Kleinnijenhuis, 2022; Pedersen, 2023). To date, a number of regional, national, and subnational jurisdictions have enacted carbon pricing initiatives in the form of either carbon taxes or cap-and-trade programmes. On the one hand, studies show that carbon pricing is effective in reducing GHG emissions (Lin and Li, 2011; Andersson, 2019; Bayer and Aklin, 2020; Bai and Ru, 2024; Martinsson et al., 2024). On the other hand, policy makers are also concerned about the potential negative impacts of carbon pricing on economic growth, employment, inflation, and the competitiveness of domestic industries in international trade.[1] This concern is amplified by the large discrepancies in carbon prices across jurisdictions around the world. In a global economy, a high local carbon price in one jurisdiction would simply move the most carbon-intensive activities elsewhere, a phenomenon known as 'carbon leakage'.[2]

The majority of empirical studies show that the enactment of carbon pricing policies does not have a discernible negative effect on aggregate economic growth.[3] However, it is reasonable to conjecture that carbon pricing policies could have a heterogeneous effect on firms and industries within an economy. Naturally, the effect should be more negative for high-

[1] As an example, the Trump administration's decision to retreat from the Paris Accord was motivated by its heavy economic costs to the US economy. In his 1 June 2017 statement on the Paris Accord, for example, the former president claimed that the cost to the economy would be 'close to three trillion dollars in lost GDP and 6.5 million in industrial jobs' (Trump, 2017).

[2] Consistent with carbon leakage, Bartram, Hou, and Kim (2022) document that financially constrained firms shifted emissions and output from California to other states after the adoption of the California cap-and-trade programme. Dai et al. (2021) document that US firms outsource part of their pollution to suppliers overseas. Ben-David et al. (2021) document that firms headquartered in countries with strict environmental policies perform their polluting activities abroad, in countries with relatively weak policies. Laeven and Popov (2023) find the introduction of a carbon tax to be associated with an increase in domestic banks' lending to coal, oil, and gas companies in foreign countries.

[3] See, for example, Metcalf and Stock (2020, 2023), Yamazaki (2017), and de Silva and Tenreyro (2021).

emission firms, which must either purchase carbon allowances to offset their emissions or downsize production to reduce their emissions. The fact that we do not observe an aggregate impact on economic growth could be because low-emission firms benefit significantly from carbon pricing policies. For example, low-emission firms may sell their unused carbon allowances to make a profit.[4] In addition, governments typically recycle revenues generated through carbon pricing back into the economy to promote the development of green technologies or business practices, which can boost the performance of low-emission firms. However, it is possible that even high-emission firms may not be materially affected by carbon pricing initiatives, if they can pass their higher operating costs to their customers, relocate their production facilities to places with more lenient carbon pricing policies, or adopt green technologies rapidly (Shapiro and Metcalf, 2023).[5] Therefore, whether the enactment of carbon pricing policies adversely affects firm performance is ultimately an empirical question and has important policy implications, as the costs of stringent carbon pricing policies may not be shared evenly across firms and households.

In this paper, we examine the economic effects of carbon pricing by conducting a comprehensive analysis of the effects of carbon pricing policies (including both carbon taxes and emission trading systems [ETSs]) on the operating performance and market value of *individual* firms around the world. To this end, we use the newly available carbon pricing data from the World Bank and combine these data with firm-level carbon emissions data from S&P Global Trucost, accounting variables from Worldscope, and stock prices from Compustat Global. Our sample includes 104,100 firm-year observations covering 16,222 unique firms across 52 countries from 2002 to 2019. Thirty-two countries had adopted some form of carbon

[4] For example, reports show that Tesla made US$1.78 billion in revenue from the sale of carbon credits in 2022. https://carboncredits.com/tesla-carbon-credit-sales-reach-record-1-78-billion-in-2022/

[5] Another reason for the nonsignificant effects could be that the average global carbon price is still far below the social cost of carbon. Currently, the global average carbon price is $6 per ton of CO_2, far below the mean social cost of carbon of US$185 per ton of CO_2 ($44–$413 per tCO_2: 5%–95% range) estimated by Rennert et al. (2022).

pricing initiative at either the national (regional) or subnational level by the end of 2019. Our first test shows that carbon pricing policies are indeed effective in reducing firm-level carbon emissions, which is consistent with prior studies documenting substantial environmental benefits of carbon pricing at the country and industry levels.

The staggered enactment of carbon pricing initiatives across jurisdictions at different time points allows us to estimate the causal effects of carbon pricing on firm performance. We create a dummy variable, *Post*, indicating years that a jurisdiction has enacted a carbon pricing policy. Our key variable of interest is the interaction term between the *Post* dummy and a firm's carbon intensity. Our main empirical specification is a difference-in-difference-in-differences (triple difference) approach, comparing the change in performance around the enactment of carbon pricing (first difference) across firms in treated versus untreated jurisdictions (second difference) and across firms with differential carbon intensity (third difference). The advantage of the triple difference approach in this context is that the third difference is arguably exogenous with respect to the adoption of carbon pricing initiatives, which are enacted at the jurisdiction level and are less likely to be influenced by individual firms' (current and expected) performance.

Our baseline results suggest that more carbon-intensive firms experience a significant reduction in profitability after their jurisdictions enact carbon pricing initiatives, compared with low-emission firms. We measure firm profitability by return on assets (*ROA*) and return on equity (*ROE*). Economically, firms with above-median carbon intensity experience a reduction of 55 (123) basis points (bps) in *ROA* (*ROE*) after the enactment of carbon pricing. This is equivalent to 13% and 6.7% of the mean and standard deviation of *ROA*, respectively, indicating that the effect is not only statistically significant but also economically meaningful.[6]

[6] The effect we estimate could potentially underestimate the economic costs, as private firms with fewer financial resources are more vulnerable to stringent climate policies.

Our baseline specification controls for firm and year fixed effects, which absorb time-invariant firm heterogeneity and aggregate trends in profitability. To mitigate the endogeneity concern that a government's decision to adopt carbon pricing policies is influenced by local economic conditions, we further include jurisdiction-year fixed effects, which absorb the effect of time-varying local economic conditions. Our baseline results are also unchanged when we include industry-year fixed effects, which absorb the effect of industry-specific trends in profitability.[7] We further conduct a dynamic effect analysis and find that the effect of carbon pricing policies is only significant in the year carbon pricing policies are enacted and in subsequent years. The insignificant pre-trend supports the parallel trend assumption underlying the triple difference estimation.

We conduct several tests to ensure the robustness of our baseline findings. First, our baseline specification uses firm-level carbon intensity as the continuous treatment variable. We show that the results are similar if we use dummy variables to indicate the treatment firms, which are those with carbon intensity above the median or in the top quartile. Second, we examine the effect of carbon taxes and ETSs separately and find that both types of carbon pricing mechanisms significantly reduce the profitability of carbon-intensive firms. Third, the results are also robust when we remove US firms from our sample, suggesting that the effect is not solely driven by US firms. Fourth, we find similar effects for firms with no foreign facilities (defined as firms without foreign assets), thus addressing the potential measurement error that a firm headquartered in a given country may have production facilities in other countries. Fifth, our main analysis focuses on scope 1 emissions, which constitute the target of most carbon pricing policies. However, carbon pricing initiatives may also affect firms with higher scope 2 and scope 3 emissions if upstream suppliers can partially pass on the costs to

[7] We group firms into 11 industries based on the Global Industry Classification Standard (GICS): Healthcare, Materials, Real Estate, Consumer Staples, Consumer Discretionary, Utilities, Energy, Industrials, Consumer Services, Financials, and Technology sectors.

downstream customers. Consistent with this conjecture, we find that firms with higher scope 2 and 3 emission intensity also experience a significant reduction in profitability after the enactment of carbon pricing, although the economic effect for these firms is smaller. Finally, recent studies show that the coefficients of staggered difference-in-differences (DD) estimation could be biased (e.g., Abraham and Sun, 2018; Chaisemartin and D'Hautfeuille, 2020). We show that the results are robust when we correct for bias using the stacked DD regression approach.

We use a complementary approach to examine the effect of carbon pricing on firm profitability. Specifically, we use the annual prices of carbon taxes and ETSs to quantify the economic effect of carbon price increases on the profitability of carbon-intensive firms relative to low-emission firms. For this test, we restrict our examination to the subsample of firms headquartered in jurisdictions with carbon pricing initiatives. We find a significant negative effect on firm profits for the price of carbon taxes, while the effect of ETS prices is not significant. This result supports our intuition that the negative effects of carbon pricing policies on carbon-intensive firms are more pronounced when the carbon price is higher.

Having established a robust negative effect of carbon pricing policies on carbon-intensive firms' profitability, we next investigate the channels through which this effect is produced. As firm profits are equal to sales minus costs, the effect could come from either an increase in operating costs or a decline in sales growth, or both. Intuitively, carbon-intensive firms could keep the same production/emissions and choose to pay carbon taxes or buy additional allowances to offset their emissions. Another way to comply with carbon pricing is to reduce emission intensity by switching to green technologies or using renewable energy, which should also manifest as higher costs. Alternatively, because a firm's level of carbon emissions is closely related to its production activity, carbon-intensive firms can also reduce the cost of complying with carbon pricing by downsizing their production, which would manifest as slower sales growth. We find that the effect of carbon pricing on firm profitability comes from both channels, as carbon-intensive firms' cost of goods increases and sales growth declines after the enactment of carbon pricing.

In addition to firm profitability, we examine several other important firm outcomes that are theoretically linked to profits, including firm value and real investments. As firm value is simply the present value of expected future cash flows, we first examine the effects of carbon pricing policies on expected future cash flows, as proxied by analysts' consensus forecasts for earnings per share (EPS) over various horizons. We find that analysts anticipate that carbon pricing policies mainly reduce the earnings of carbon-intensive firms relative to low-emissions firms in the short term but do not exert a negative effect on long-term earnings growth.

We then test whether carbon pricing policies lead to a higher cost of capital for carbon-intensive firms. Consistent with the 'carbon premium' hypothesis (Bolton and Kacperczyk, 2021, 2023), we find that carbon-intensive firms experience a significant increase in the cost of debt financing and implied cost of equity. Using an earnings call-based measure of firm exposure to climate risk (Sautner et al., 2023), we further show that the increased carbon premium is likely to be explained by firms' increased exposure to climate regulatory risk (but not to physical risks). Finally, using Tobin's q and annual stock return as measures of firm value change, we find that carbon-intensive firms experience a significant reduction in firm value, which can be almost entirely attributed to higher discount rates and lower expected cash flows.

The q theory of investment predicts a strong relationship between firms' market value and their investment rates. As carbon pricing policies reduce the value of carbon-intensive firms, we examine how firm investments respond to the enactment of such policies. We use multiple measures of firm investment, namely capital expenditures, R&D expenses, and number of employees, which represent investment in physical assets, growth opportunities, and human capital, respectively. Consistent with the prediction of the *q* theory of investment, we find that carbon-intensive firms significantly reduce all three types of investments after the enactment of carbon pricing policies.

We conduct cross-country analyses to shed light on how country characteristics affect the costs of carbon pricing policies. First, we conduct a regional analysis for each of the regions of Asia, North America, and Europe, using the rest of the world as the benchmark. We find the effect of carbon pricing on firm profitability to be negative for all three regions, with the strongest effect observed for firms headquartered in North America. The effect is weaker and not significant for Europe, which is probably due to the free allocation and oversupply of emission permits in the early phases of the European Union (EU) ETS. Second, we explore cross-country variations in exposure to fossil fuel energy. The results show that the negative effect of carbon pricing on firm profits is stronger for firms headquartered in countries with larger fossil fuel energy sectors and where per capita energy consumption is higher. Third, we explore the interaction between a country's exposure to physical risks and its exposure to transition risks. Using country-level physical climate risk measures from the Notre Dame Global Adaptation Initiative, we find that the profitability effect of carbon pricing does not vary with a country's exposure to physical risks. One possible explanation for this result is that physical risks are mainly determined by the climate system of the entire planet and are unlikely to be influenced by the carbon pricing policies of a single jurisdiction.

The rest of the paper proceeds as follows. Section 2 provides the institutional background of carbon pricing initiatives and highlights our contribution to the literature. Section 3 details the datasets used in this study and presents the summary statistics. Section 4 presents our main results regarding the effect of carbon pricing on firm profitability. We examine the effect of carbon pricing on firm value and real investments in Section 5. Section 6 concludes the paper.

2. Institutional Background and Contribution to the Literature

2.1 Carbon pricing background

GHG emissions are a key driver of climate change and have continued to increase globally in recent years. With current climate policies, standard climate models predict an increase of 3°C in global temperature compared with pre-industrial levels by the end of this century (IPCC, 2014). Climate policies must therefore be enhanced to reduce GHG emissions (Stern, 2008). Carbon pricing can be an effective policy tool to reduce GHG emissions (Kohlscheen et al., 2021). Higher carbon prices make renewable energy more competitive, provide incentives to reduce emissions, and reduce demand for carbon-intensive fuels (Martin et al., 2016).

The main types of carbon pricing policies are carbon taxes and ETSs. Carbon taxes entail governments setting a price on carbon by defining a tax rate on GHG emissions or – more commonly – on the carbon content of fossil fuels and let private agents determine the quantities of emissions. A carbon tax is an attractive option for jurisdictions with limited administrative capacity or resources available for implementation or that want to introduce carbon pricing quickly. The first carbon taxes were introduced in Finland and Poland in 1990.

The ETS has been considered a possible tool for mitigating GHG emissions since the early 1990s and formed a key part of the Kyoto Protocol agreement. An ETS can take the form of a cap-and-trade or baseline-and-credit ETS. In cap-and-trade systems, governments cap the total level of GHG emissions and allow firms with low emissions to sell their extra allowances to larger emitters. By creating supply and demand for carbon allowances, an ETS establishes a market price for GHG emissions. The cap helps ensure that the required emissions reductions take place to keep emitters (in aggregate) within their pre-allocated carbon budget (World Bank, 2021). Unlike carbon taxes, ETSs provide certainty as to the quantity of emissions reduced but not over the carbon price. They also provide flexibility regarding where and when emissions reductions occur, which can lower mitigation costs and make international cooperation on climate polices easier. However, an ETS is usually more complex to create and administer than carbon taxes, as it involves additional infrastructure and administrative setup. The EU established an ETS in 2005; it is currently the largest carbon market in the world and covers 40% of the region's GHG emissions. Furthermore, China established eight regional pilot ETSs in 2013 – namely Beijing, Shanghai, Tianjin, Chongqing, Shenzhen, Guangdong, Hubei, and Fujian – all of which preceded the national ETS established in 2021.

2.2 Contribution to the literature

Our paper contributes to several strands of the literature. First, we contribute to a growing literature that empirically examines the economic effects of carbon pricing policies. Studies examining the effects of carbon pricing on macroeconomic aggregates generally find no discernible negative effects on economic growth, employment, or inflation. For example, Metcalf and Stock (2020, 2023) study the macroeconomic effects of carbon taxes in European countries. They find no robust evidence of a negative effect of carbon taxes on employment or GDP growth. Yamazaki (2017) finds that the British Columbia carbon tax generated, on average, a small but statistically significant 0.74% annual increase in employment over the 2007–2013 period. Moessner (2022) shows that higher carbon prices have not led to large increases in headline inflation. Furthermore, de Silva and Tenreyro (2021) document that the effect of climate policies on GDP growth or inflation is largely nonsignificant.[8] One exception is Känzig (2022), who uses carbon policy shocks to identify the causal effects of carbon price change on macroeconomic quantities. He finds that a tighter carbon pricing regime leads to a significant increase in energy prices and a fall in economic activity.

[8] These findings are in stark contrast with most theoretical studies, which estimate the economic impacts of carbon pricing using computable general equilibrium (CGE) models and show non-trivial negative effects of carbon pricing on the economy.

At the micro level, the evidence is also inconclusive. For example, Martin et al. (2014) estimate the effect of a carbon tax on manufacturing plants using panel data from the UK production census and find no significant effects on employment, revenue, or plant exit. In contrast, Känzig (2022) finds that a tighter carbon pricing regime leads to a significant reduction in poor households' income and consumption. Kumar and Purnanandam (2022) document that after the implementation of the Regional Greenhouse Gas Initiative (RGGI), publicly traded power utility companies in the affected states experienced a drop in profitability but a higher market-to-book ratio. Compared with prior studies focusing on ETSs or carbon taxes within a single jurisdiction, we conduct a more comprehensive analysis of the economic effects of both ETS and carbon tax initiatives on individual firms around the world. While single-jurisdiction settings are useful in ruling out confounding factors, a cross-country study is important, as mitigating climate change requires policy coordination on a global scale. Our paper highlights the large distributional effects of carbon pricing policies at the firm level, which complements prior studies focusing on their macroeconomic impacts.

Second, our study provides causal evidence for the pricing of transition risks in financial markets. Bolton and Kacperczyk (2021, 2023) show that carbon-transition risks are priced in the US and global equity markets, as they find that stocks of high-emission firms earn higher average returns than those of low-emission firms. Using earnings conference call data to construct firm-level exposure to climate change, Sautner et al. (2023) find an unconditionally positive risk premium associated with firm-level climate change exposure. However, several recent studies challenge the existence of a carbon premium in stock markets (Zhang, 2022; Atilgan et al., 2023; Aswani et al., 2024).[9] Such inconclusive findings in the literature may

[9] Recent studies also examine the pricing of climate transition risks in fixed income markets. While Seltzer, Starks, and Zhu (2022) show that environmental policy risk is priced in the yield of US corporate bonds, Duan, Li, and Wen (2023) and Kontz (2022) provide evidence that carbon risk is not fully priced in the returns of US corporate bonds and securitised auto loans, respectively. Ilhan, Sautner, and Vilkov (2021) show that downside tail risk associated with climate policy uncertainty is priced in options markets.

arise because traditional asset pricing methodologies (such as portfolio sorting and Fama–MacBeth regressions) cannot fully address omitted variable bias. Unlike these studies, we exploit the staggered adoption of carbon pricing initiatives across multiple jurisdictions and use a triple difference approach and various fixed effects to mitigate omitted variable bias. We show that the carbon premium increases after the enactment of carbon pricing initiatives in a jurisdiction, consistent with Bolton and Kacperczyk (2021).

Several studies specifically examine how carbon pricing initiatives affect stock returns, with inconclusive evidence. For example, Oestreich and Tsiakas (2015) find that during the early phase of the EU ETS, firms that received free carbon emission allowances, on average, significantly outperformed firms that did not. Bushnell et al. (2013) find that firms with higher carbon intensity obtained higher abnormal stock returns following the unexpected collapse of EU carbon prices in April 2006. These studies suggest that carbon-intensive firms benefit from carbon pricing policies more than low-emission firms do, which may not be generalisable to other countries, due to the specific design of the EU ETS in its early phases. In contrast, Millischer et al. (2023) and Bolton et al. (2023) show that an increase in carbon prices of the EU ETS is associated with a decrease in the contemporaneous stock prices of carbon-intensive firms, especially for firms with a significant shortfall in emission allowances. Our paper covers a much broader sample of carbon pricing initiatives around the world than those used in the aforementioned studies, and we examine the effects on both firms' financial performance and operating performance. We find that carbon-intensive firms experience a decline in firm value relative to low-emission firms after the enactment of carbon pricing policies, which is driven by both the cash flow and discount rate channels.

Finally, our paper is also related to the broader environmental economics literature that examines the real and financial effects of environmental policies. Studies show that stringent environmental policies reduce firm productivity (He, Wang, and Zhang, 2020), restrict bank lending (Ivanov, Kruttli, and Watugala, 2023), and lead to more conservative capital structure (Dang, Gao, and Yu, 2022) but also encourage more R&D investments and green patents (Brown et al., 2022; Gugler et al., 2024). Bartram, Hou, and Kim (2022) and Dai et al. (2021) show that environmental policies without coordination among jurisdictions lead to firms' opportunistic behaviour, such as relocation and outsourcing of polluting activities to jurisdictions with more lenient environmental regulations. Ramadorai and Zeni (2024) highlight the important role of firms' reported beliefs about future climate regulations in influencing their emissions reduction activities. Our paper differs from these studies by investigating how carbon pricing policies affect the *relative* performance and market value of firms, conditional on their carbon intensity.

3. Data and Summary Statistics

3.1 Data

We first obtain data on firm-level carbon emissions from the S&P Global Trucost database, covering the 2002–2019 period.[10] Trucost classifies firms' carbon emissions into three scopes, following the Greenhouse Gas Protocol. Scope 1 emissions are direct GHG emissions from sources that are controlled or owned by an organisation (e.g., emissions associated with fuel combustion in boilers, furnaces, and vehicles). Scope 2 emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling by firms. Scope 3 emissions, which are mostly estimated using an input–output model, include indirect emissions produced by the extraction and production of purchased materials and fuels, electricity-related activities not covered by Scope 2 emissions, outsourced activities, and waste disposal, among others. Trucost reports both carbon emissions, measured in tons of CO_2 equivalent, and CO_2 emission

[10] Trucost collects firm-level emissions data from various sources, including company reports, environmental reports (CSR/ESG reports, the Carbon Disclosure Project, Environmental Protection Agency filings), and data from company websites. When a covered firm does not publicly disclose its carbon emissions, Trucost estimates its annual carbon emissions based on an environmental profiling model.

intensity (i.e., tons of CO_2 emissions divided by a firm's total revenue in millions of US dollars) for each scope.

Second, we obtain data on carbon pricing initiatives at the regional, national, and subnational levels between 1990 and 2019 from the World Bank Carbon Pricing Dashboard.[11] Carbon pricing initiatives mainly consist of two types: carbon taxes and ETSs. By 2023, 39 national jurisdictions and 33 subnational jurisdictions had carbon pricing initiatives in place, covering 11.66 Gt of CO_2 equivalent, or 23% of global GHG emissions.

Table 1 lists the names and enactment years of the carbon pricing initiatives at the regional and national levels in Panel A and at the subnational level in Panel B. By the end of 2019, 32 countries in our sample had implemented some form of carbon pricing initiative at either the national or subnational level. The earliest carbon pricing initiatives were the carbon taxes established in Finland and Poland in 1990. The EU established its ETS in 2005, and China established eight regional pilot ETSs in the 2010s, which preceded its national ETS in 2021. The US has no carbon pricing initiatives at the federal level but has several carbon pricing initiatives at the subnational level, including the RGGI and the California Cap-and-Trade Program.

Finally, we obtain firm-level accounting data from the Worldscope database, stock price information from Compustat Global, and analyst forecast data from I/B/E/S. We also obtain country-level macroeconomic data from IMF, legal institution data from the International Country Risk Guide (ICRG), energy structure data from the World Bank, and country-level physical climate risk data from the Notre Dame Global Adaptation Initiative.

[11] These data are available for download at https://carbonpricingdashboard.worldbank.org/map_data.

3.2 Descriptive statistics

To construct our sample, we merge the Trucost database with the Worldscope database based on the ISIN code, and with IMF and ICRG databases based on country name. After filtering out firm-years with missing values, we further remove firm-year observations based on the following criteria: (1) stock price less than one unit of local currency, (2) market capitalisation less than US$10 million at the end of the fiscal year, (3) negative net sales and shareholder equity, and (4) countries with fewer than 10 unique firms. Our final sample comprises 104,100 firm-year observations covering 16,222 unique firms from 52 countries over the 2002–2019 period.

Table IA.1 in the Online Appendix presents the distribution of our sample across countries. Column (1) reports the number of firm-years in each country. Column (2) reports the percentage of firm-years from each country. Column (3) reports the number of unique firms in each country. Columns (4) to (6) report the average firm-level carbon intensity in each country. The US accounts for the largest percentage of firm-year observations (20.95%) and unique firms (3,208), while Kenya has the smallest number of firm-year observations (0.07%) and unique firms (11). The country with the highest mean (scope 1) carbon intensity is the Netherlands (1,634.73), while the country with the lowest average carbon intensity is Sweden (54.75). The average Scope 1, Scope 2, and Scope 3 emission intensity levels across all countries in our sample are 268.26, 43.48, and 191.33, respectively. Table 2 presents the summary statistics of the main variables used in this study. All of the continuous variables in our sample are winsorised at the 1% level. The average (median) *ROA* and *ROE* values in our sample are 0.04 (0.04) and 0.09 (0.10), respectively. The average (median) Tobin's q is 1.80 (1.31). The average (median) price of carbon taxes and ETSs are $31 ($26.7) and $15.3 ($15.6), respectively.

3.3 Are carbon pricing initiatives effective in reducing emissions?

As the main policy objective of carbon pricing is to curb GHG emissions, the first question we examine is whether the enactment of carbon pricing initiatives reduces GHG emissions in the economy. Previous studies find evidence that carbon pricing policies indeed lead to lower emissions at the industry and firm levels (Andersson, 2019; Bayer and Aklin, 2020; Bai and Ru, 2024; Martinsson et al., 2024). In this subsection, we examine the effect of carbon pricing initiatives on firm-level carbon intensity. We use the DD approach with the following specification:

$$Log(Intensity)_{i,c,t} = \beta_0 + \beta_1 Post_{c,t} + \gamma' \boldsymbol{X}_{\boldsymbol{i,c,t}} + \boldsymbol{k}' \boldsymbol{Z}_{\boldsymbol{c,t}} + \varepsilon_{i,t} \qquad (1)$$

The dependent variable is the natural log of carbon intensity of firm *i* headquartered in jurisdiction *c* in year *t*. $Post_{c,t}$ is a dummy variable equal to one if jurisdiction *c* has implemented some form of carbon pricing initiative (either a carbon tax or ETS initiative) in year *t*. $\boldsymbol{X}_{\boldsymbol{i,c,t}}$ represents a set of firm-level control variables, namely *Log(Assets)*, *Leverage*, *Cash*, *Sales growth*, *CapEx_assets*, and *R&D_sales*.[12] $\boldsymbol{Z}_{\boldsymbol{c,t}}$ represents a list of country-level variables, namely *Log(GDP per capita)* and *Law and order*. We also include firm and year fixed effects and cluster all standard errors at the firm level.

Table IA.2 in the Online Appendix reports the results. Columns (1) and (2) report the results with Scope 1 emission intensity as the measure of carbon emissions. Consistent with country-level studies (Bai and Ru, 2024), we find that, on average, firms significantly reduce their Scope 1 emission intensity after a jurisdiction adopts carbon pricing initiatives.[13] The coefficient suggests that the reduction in carbon intensity represents 4.35% of the standard deviation of carbon intensity. As presented in columns (3) and (4), we find similar evidence that firms reduce their Scope 2 emission intensity, although the economic effect is smaller than

[12] Appendix A provides detailed definition for these variables.

[13] Interestingly, our estimates based on firm-level data are similar to the effect observed using country-level emission data, as reported in Table 2 of Bai and Ru (2024).

for Scope 1 emissions. Interestingly, as shown in columns (5) and (6), carbon pricing policies have no discernible effect on Scope 3 emission intensity, consistent with the fact that most carbon pricing initiatives do not cover Scope 3 emissions. Overall, carbon pricing policies are effective in reducing firms' GHG emissions, which should benefit society by mitigating climate change. In the next section, we examine the potential costs that firms pay to achieve lower emissions.

4. Effects of Carbon Pricing on Firm Profitability

4.1 Baseline results

The focus of our study is to examine the effects of carbon pricing initiatives on firms' operating performance and value. To this end, we run the baseline specification as follows:

$$Y_{i,c,t} = \beta_0 + \beta_1 Log(Intensity1 + 1)_{i,c,t} + \beta_2 Post_{c,t} + \beta_3 Post_{c,t} \times Log(Intensity1 + 1)_{i,c,t} + \gamma' \boldsymbol{X_{i,c,t}} + k' \boldsymbol{Z_{c,t}} + \varepsilon_{i,c,t} \quad (2)$$

where i, c, and t indicate the firm, jurisdiction, and year, respectively. $Y_{i,c,t}$ indicates the outcome of firm i headquartered in jurisdiction c in year t, as measured by profitability (*ROA*/*ROE*), Tobin's q, or investments. The control variables are the same as in equation (1). In the baseline model, we include year and firm fixed effects, which account for aggregate trends and time-invariant heterogeneity in firm performance. We cluster all standard errors at the firm level in the main specification, and the results are robust when we use alternative ways to cluster standard errors.

The key variable of interest in this specification is the interaction between the *Post* dummy and firm-level carbon intensity. The parameter of interest is β_3, which should be significant and negative when the outcome variable is firm profitability. With the triple difference estimator, we essentially compare the change in performance around the enactment of carbon pricing (first difference) across firms in treated versus untreated jurisdictions (second difference) and across firms with differential carbon intensity (third difference). The third difference is arguably more exogenous with respect to carbon pricing initiatives, which are enacted at the jurisdiction level and unlikely to be influenced by individual firms' (current and expected) performance.

Table 3 presents the results. Columns (1) and (3) report the results without any control variables. Consistent with our conjecture, the coefficients on $Post_{c,t} \times Log(Intensity1 + 1)_{i,c,t}$ are negative and significant at 1% level for *ROA* and *ROE*, indicating that the profitability of carbon-intensive firms is significantly reduced relative to that of low-emission firms after their jurisdictions adopt carbon pricing policies. In columns (2) and (4), we add the control variables to the regression model. We find that the coefficients of the interaction term are similar across specifications and that the level of statistical significance increases.

To gauge the economic effect, we create a dummy variable, *D(Intensity1>Median)*, which represents firms with above-median Scope 1 emission intensity in a given jurisdiction. We then interact this dummy with the *Post* dummy and run the same triple difference regression. Panel A of Table IA.3 reports the results. The negative and significant coefficients on *Post*D(Intensity1>Median)* suggest that the baseline results hold, when using the dummy treatment indicator. With a coefficient of -0.0055 and -0.0123 for *ROA* and *ROE*, respectively, these results suggest that firms with above-median carbon intensity experience a reduction of 55 (123) bps in *ROA* (*ROE*) relative to firms with below-median carbon intensity after carbon pricing initiatives are enacted. The economic effect is non-trivial, as it is equivalent to 13% and 6.7% of the mean and standard deviation of firm profitability in our sample, respectively.[14]

[14] We conduct a back-of-the-envelope calculation for the effects of carbon pricing on firm profits. The median carbon tax and ETS prices are US$26 and US$15, respectively. Because the carbon price is 0 before the enactment of carbon pricing, the change in median carbon prices from the pre- to the post-enactment period is around US$20.5 per ton of CO_2. The average Scope 1 emission intensity in our sample is 268 tons per million US$ of sales. Evaluating at the mean, the average dollar cost of carbon pricing is 0.549% of firm sales. If we assume that the average net profit margin is 5%, the average cost of carbon pricing is 11% of firm profits. This is close to the economic effect we report in this paper.

The triple difference estimator compares the change in performance of carbon-intensive firms relative to that of low-emission firms but does not tell us whether the difference is also driven by low-emission firms benefiting from carbon pricing policies. To test the effects of carbon pricing on low- and high-emission firms separately, we create two dummy variables, *D(Intensity1=Top Quartile)* and *D(Intensity1=Bottom Quartile)*, indicating firms with carbon intensity in the top and bottom quartiles of the distribution within a country, respectively. We then interact these two dummies with the *Post* dummy and run the triple difference regression. Panel B of Table IA.3 shows that the coefficients on *Post*D(Intensity1=Top quartile)* are negative and significant across all specifications, while the coefficients on *Post*D(Intensity1=Bottom quartile)* are not significant and positive. This suggests that carbon pricing mainly exerts a negative effect on the profits of carbon-intensive firms relative to firms with average carbon intensity, while its beneficial effect on low-emission firms is smaller and less significant.

Overall, these results suggest that carbon-intensive firms experience a significant reduction in profitability relative to low-emission firms, indicating that they are not able to fully pass on the increased costs arising from carbon pricing to their customers or undo the negative effect through relocation or outsourcing to countries with laxer carbon pricing policies.

4.2 Dynamic effect analysis

The validity of the triple difference approach depends crucially on the parallel trend assumption, that is, the assumption that in the absence of carbon pricing initiatives, the profitability of the treated firms would have evolved in the same way as that of the control firms. In this subsection, we conduct a dynamic effect analysis to examine whether the parallel trend assumption holds. Specifically, we create time dummies to flag the year relative to the enactment year of the carbon pricing initiatives. *Before*$^{-t}$ is a dummy variable equal to one in the *t* year before the enactment of the carbon pricing initiative, and zero otherwise. *Current* is a dummy variable equal to one for the enactment year of the carbon pricing initiative, and zero otherwise. $After^{+t}$ is a dummy variable equal to one in the *t* (*t* = 1, 2) year after the enactment of the carbon pricing initiative, and zero otherwise. $After^{3+}$ is a dummy variable equal to one for the third and consecutive years after the enactment of the carbon pricing initiative, and zero otherwise. We then re-estimate equation (2) by interacting firms' carbon intensity with these seven event time indicators.

Table 4 reports the results. For both measures of firm profitability, the coefficients on the interaction terms between carbon intensity and the years before the enactment of carbon pricing are close to 0 and not statistically significant. This supports the parallel trend assumption that before the enactment of carbon pricing policies, carbon-intensive firms exhibit trends in profitability similar to those of low-emission firms. Importantly, the coefficients on the interaction terms start to turn negative and significant in the enactment year of carbon pricing, suggesting the immediate impact of carbon pricing on firm performance. Finally, the interaction terms between carbon intensity and the years after the enactment of carbon pricing are all negative and significant, implying a long-lasting effect of carbon pricing on firm profits.

To show the dynamic effect of carbon pricing initiatives on the profitability of carbon-intensive firms, Figure 1 plots the estimated coefficients (along with the 95% confidence intervals) of the seven interaction terms from Table 4. Overall, the nonsignificant pre-trend suggests that the negative effect of carbon pricing policies on the profitability of carbon intensive firms is plausibly causal.

4.3 Stacked regression

Recent studies argue that the staggered DD approach could be biased (e.g., Abraham and Sun, 2018; Chaisemartin and D'Hautfeuille, 2020).[15] We first follow the recommendation of Baker, Larcker, and Wang (2022) to evaluate the likelihood of bias. Baker, Larcker, and Wang (2022) show that the potential biases associated with a staggered DD estimate are less severe if the percentage of never-treated observations is high. As the never-treated observations account for 40.8% of our sample, the potential biases associated with our triple difference estimation are less problematic.[16]

Following Cengiz, Dube, Lindner, and Zipperer (2019), we use the stacked regression approach to further address the potential biases associated with the staggered DD approach.[17] To implement the idea, we first drop all of the firms treated before the first year in our sample, as they do not help uncover the average treatment effect. Then, for each treatment event, we create a separate dataset of the firms treated by the event and all never-treated firms and restrict the sample period to six years before and after the relevant event. Finally, all of the event-specific datasets are stacked together to obtain the stacked database.

We re-run the triple difference regression using the stacked dataset and report the results in Table IA.4 in the Online Appendix. We include cohort-firm and cohort-year fixed effects in all of the specifications and cluster standard errors at the firm-cohort level. Across all of the specifications, the coefficient on the interaction term between *Post* and *Log(Intensity1+1)* is negative and significant at the 1% level for both *ROA* and *ROE*. In terms of economic magnitude, the negative effect of carbon pricing is about 20% smaller than in the baseline

[15] The coefficients of the two-way fixed effects (TWFE) DD regressions are a weighted average of many 2x2 DD regressions. In some of these 2x2s, the early treated firms act as effective controls for the late treated firms, which may lead to a biased estimate if there are dynamic treatment effects.
[16] The decomposition analysis of the static TWFE DD estimator proposed by Goodman-Bacon (2021) is not possible in our setting because the database is unbalanced with gaps.
[17] The idea is to create separate, event-specific datasets with the treated cohort and all never-treated firms (i.e., clean controls) within the treatment window and then stack all separate, event-specific datasets together.

results in Table 3, suggesting that the stacked regression partially corrects for the downward bias inherent in the staggered DD approach.

4.4 Robustness tests

We conduct several robustness checks. First, we examine separately the effect of carbon taxes and ETSs on firm profitability. To this end, we create two variables, *Post_Tax* and *Post_ETS*, which are dummy variables indicating the years when a jurisdiction has implemented a carbon tax and an ETS, respectively. Panel A of Table 5 shows that the coefficients on *Post_Tax*Log(Intensity+1)* and *Post_ETS*Log(Intensity+1)* are negative and significant across all specifications. This suggests that both types of carbon pricing initiatives reduce the profitability of carbon-intensive firms relative to low-emission firms.

Second, in Panel B of Table 5, we use more stringent fixed effects to mitigate the endogeneity concern that a government's decision to enact carbon pricing policies may be affected by local economic conditions. In columns (1) and (3), we include *Jurisdiction-Year* fixed effects to absorb the confounding effect of local macroeconomic conditions and find that the coefficients on *Post*Log(Intensity+1)* remain negative and significant at the 1% level. With *Jurisdiction*Year* fixed effects, the results suggest that the profitability of carbon-intensive firms is significantly reduced after the enactment of carbon pricing, relative to low-emission firms headquartered in the same jurisdiction in the same year. Columns (2) and (4) show similar results when we include *Industry-Year* fixed effects, which absorb industry-specific trends in profitability such as energy price shocks.

Third, one may be concerned that our main finding is predominantly driven by US firms, which account for around 20% of our sample. Therefore, we re-run the baseline regression after excluding US firms from our sample. Panel C of Table 5 shows that the results still hold, and the economic effect is similar to the baseline results.

Another concern for our baseline test is that firms headquartered in a given country may have facilities located in foreign countries that are not subject to the headquarters' domestic carbon pricing policies. However, this measurement error in firm location should only bias us against finding any significant negative effect of carbon pricing on the performance of carbon-intensive firms. To further address this concern, we select firms with no foreign facilities (identified as firms without foreign assets in Worldscope) and re-run the baseline test. Panel D of Table 5 shows results similar to the baseline findings, suggesting that the measurement error in firm location does not significantly bias our results.

In our baseline analyses, we use Scope 1 emission intensity to define firms' treatment status, as many carbon pricing policies only cover Scope 1 emissions.[18] However, carbon pricing initiatives may also affect firms with high Scope 2 and 3 emissions if upstream firms can partially pass on the associated costs to their downstream customers. For example, a manufacturing firm with high Scope 2 emissions, by definition, relies heavily on a utility provider for electricity, which could be generated from burning fossil fuels. After carbon pricing policies are adopted, the utility company must pay higher operating costs to generate the same amount of electricity and may decide to (partially) pass on the costs to its customer – the carbon-intensive manufacturing firm. We explore this question by using Scope 2 and 3 emission intensity to define firms' treatment status and present the results in Panel E of Table 5. Columns (1) and (2) show that the coefficients on *Post*Log(Intensity2+1)* and *Post*Log(Intensity3+1)* are significant and negative for *ROA*, while columns (3) and (4) show a much weaker effect for *ROE*. This evidence suggests that upstream firms, which are the most affected by carbon pricing policies, can partially pass on the increased costs to their downstream firms through the energy price and the supply chain.

[18] For example, China's national ETS only covers approximately 2,000 companies from the power sector with annual emissions of more than 26,000 tCO_2.

Finally, we re-run the baseline regression with alternative ways of clustering the standard errors. Panel F of Table 5 shows the results, which are robust when we cluster standard errors at the jurisdiction, jurisdiction and year, and firm and year levels.

4.5 Effect of carbon prices on firm profitability

Our triple difference tests essentially examine whether the existence of any carbon pricing policies affect firm performance, regardless of the carbon price level. However, there is significant heterogeneity in carbon prices across jurisdictions, and it is natural to conjecture that the economic impacts of carbon pricing should also depend on the carbon price level. In this subsection, we take a complementary approach by using the annual prices of carbon taxes and ETSs to quantify the economic effect of changes in carbon prices on the profitability of carbon-intensive firms relative to low-emission firms. The key variables of interest for this test are the interactions between a firm's Scope 1 emission intensity with two variables, *Log(Carbon tax price+1)* and *Log(ETS price+1)*. Panel A of Table IA.5 reports the results using the full sample. We set the carbon price in jurisdictions without any form of carbon pricing initiative at 0. The coefficients on the two interaction variables, *Log(Carbon tax price+1)*Log(Intensity1+1)* and *Log(ETS price+1)*Log(Intensity1+1)*, are negative and significant across all specifications, with similar economic magnitudes. Panel B shows similar findings for carbon tax prices when we restrict the analysis to the subsample of firms headquartered in jurisdictions with carbon pricing in place. However, the effect of ETS prices is negative but not statistically significant.[19] This result supports our prediction that the negative effects of carbon pricing policies on the performance of carbon-intensive firms are more pronounced when the average carbon price in the jurisdiction is higher.

[19] The nonsignificant effect of ETS prices may be due to the fact that ETS prices are determined by the demand and supply of carbon allowances. While a lower supply of carbon credits should increase costs for carbon-intensive firms, a higher demand for carbon credits usually occurs when carbon-intensive firms are doing well, thereby biasing the ETS price coefficient upward.

4.6 Carbon pricing and components of firm profits

We next explore the channels through which carbon pricing initiatives affect firms' profitability. As firm profits are calculated as sales minus costs, this effect comes from either an increase in costs, a decline in sales growth, or both. In practice, carbon-intensive firms can use several approaches to comply with carbon pricing policies. For example, they can keep the same level of production and emissions, which necessitates either paying carbon taxes or buying allowances to offset their excess emissions. As the level of carbon emissions is closely related to the scope of a firm's production activities, carbon-intensive firms can also reduce their regulatory costs by downsizing their production, resulting in lower sales growth. Another way to comply with carbon pricing is to reduce emission intensity by switching to green technologies or using renewable energy, which could manifest as higher costs.

To test which channels lead to the observed reduction in profits, we re-run the baseline regression by replacing firm profits with three variables that capture firm sales and costs. Table 6 reports the results. The dependent variables are the cost of goods sold divided by sales (*CGS_sales*) in column (1); annual sales growth (*Sales growth*) in column (2); and selling, general, and administrative expenses (SG&A) divided by sales (*SGA_sales*) in column (3). Column (1) shows that the coefficient on *Post*Log(Intensity1+1)* is 0.0025 (t = 1.797), suggesting that carbon-intensive firms experience an increase in operating costs following the enactment of carbon pricing initiatives. Column (2) reports that the coefficient on *Post*Log(Intensity1+1)* is -0.0039 (t = -1.962), suggesting that carbon-intensive firms also experience slower sales growth after their jurisdictions adopt carbon pricing. Column (3) shows that the coefficient on *Post*Log(Intensity1+1)* is -0.0013 (t = -1.140), suggesting that the enactment of carbon pricing initiatives does not significantly influence the SG&A components of operating costs.

Overall, we conclude that the negative impact of carbon pricing initiatives on firm profits is driven by both an increase in the cost of goods sold and a decline in sales growth for carbon-intensive firms relative to low-emission firms.

4.7 Effects of carbon pricing on industry-level profitability

In this subsection, we conduct an analysis at the industry level to assess the distributional effects of carbon pricing across industries. We first construct average profitability measures and all of the control variables at the jurisdiction-industry-year level, where industry is defined as 11 Global Industry Classification Standard (GICS) sectors. Our key variable of interest is the interaction of the *Post* dummy with the natural log of industry-average carbon intensity (*log(Average intensity1+1)*).

Table IA.6 in the Online Appendix shows that the industry-level results are generally similar to the firm-level results. Columns (1) and (2) shows that relative to low-emission industries, carbon-intensive industries experience a significant reduction in *ROA* and *ROE*, respectively, after a jurisdiction enacts carbon pricing policies.[20] Columns (3) and (4) show that the reduction in industry-level profitability comes from both an increase in the cost of goods sold and lower sales growth, although the effect on cost of goods sold is less significant. These results are consistent with the firm-level results and suggest that a significant portion of firm-level effects of carbon pricing policies occur at the industry level.

4.8 Cross-country heterogeneity tests

One important advantage of a global setting is that we can exploit cross-country heterogeneity to further examine which countries are likely to see a greater effect of carbon pricing policies. First, given that regions differ in their exposure to transition risks and adaption

[20] The mean values of industry-average *ROA* and *ROE* are 5.1% and 12.1%, respectively.

capabilities, we conduct a cross-sectional analysis based on geographic regions. To this end, we create three dummy variables, *Asia*, *North America*, and *Europe*, and use the remaining countries not from these regions as the benchmark. We re-run the baseline regression by interacting these three dummy variables with *Post*Log(Intensity1+1)* and present the results in Panel A of Table 7. We find that the coefficients are negative for all three triple interaction variables and that the effect is the strongest and most significant for North America. The interaction effect is weaker and not significant for Europe, which is probably due to the free allocation and oversupply of emission permits in the early phase of the EU ETS (Bushnell et al., 2013).

Second, because the main policy objective of carbon pricing is to reduce the economy's reliance on fossil fuels, we expect the effect of carbon pricing on firm performance to vary with countries' exposure to fossil fuel energy. We use two variables, *Energy intensity* and *Energy use*, to measure a country's exposure to fossil fuel energy. *Energy intensity* is energy consumption per capita, which measures the expected demand for fossil fuel energy per person in a country. *Energy use* is the kg of oil equivalent per capita, which represents the amount of fossil fuels consumed per person in a country. We re-run the baseline regression by interacting these two variables with *Post*Log(Intensity1+1)* and present the results in Panel B of Table 7. Consistent with our expectation, the negative effect of carbon pricing on firm profits is indeed stronger for firms in countries with larger fossil fuel energy sectors and where consumption of energy per capita is high.

Our third cross-country test exploits the interaction between a country's exposure to physical climate risk and transition risk. In our setting, climate transition risk is measured by the enactment of carbon pricing initiatives. We use two country-level indexes, *ND_vulnerability* and *ND_gain*, from the Notre Dame Global Adaptation Initiative to capture a country's exposure to physical risk.[21] We run the baseline regression by interacting the two country variables with *Post*Log(Intensity1+1)*. Panel C of Table 7 shows no significant difference in the effect of carbon pricing conditional on a country's exposure to physical risk. This evidence is consistent with the fact that physical risks are mainly determined by the climate system of the entire planet and are thus less likely to be influenced by climate policies in a single jurisdiction.

5. Effects of Carbon Pricing on Firm Value and Real Investments

Having established a strong negative effect of carbon pricing policies on the profitability of carbon-intensive firms, we next examine several other important firm outcomes that are theoretically related to profits, such as firm value and real investments. As firm value is determined by the present value of expected future cash flows, we first examine the effects of carbon pricing on expected future cash flows and the cost of capital, in subsections 5.1 and 5.2, respectively. In subsections 5.3 and 5.4, we further examine the effect of carbon pricing on firm value and real investments, respectively.

5.1 Carbon pricing and earnings expectations

In the previous section, we show that carbon pricing policies reduce the realised profits of carbon-intensive firms. In this subsection, we examine whether carbon pricing policies also lead investors to lower their expectations regarding the future cash flows of carbon-intensive firms relative to low-emission firms. We use analysts' consensus forecasts for annual EPS one to three years ahead as proxies for investors' expectations regarding short-term earnings. We use the consensus EPS forecasts available in the first month after the annual earnings announcement dates and scale them by lagged stock prices. In addition to these short-term EPS

[21] Specifically, *ND_vulnerability* reflects the propensity or predisposition of human societies to be negatively affected by climate hazards. *ND_gain* represents a country's vulnerability to climate change and other global challenges, in combination with its readiness to improve its resilience.

forecasts, we examine whether carbon pricing initiatives affect analysts' forecasts for long-term earnings growth (*LTG*).

Table 8 reports the results. Columns (1) to (3) show that the coefficients on *Post*Log(Intensity1+1)* are negative and significant for 1- to 3-year ahead EPS forecasts, while column (4) shows that the coefficient on *Post*Log(Intensity1+1)* is not significant for *LTG* forecasts. This suggests that analysts expect carbon pricing policies to reduce carbon-intensive firms' earnings in the short term but not to have a negative effect on their long-term earnings growth, potentially because firms can adapt in the long term by adopting low-carbon business practices or green technologies. Economically, after carbon pricing initiatives, a one standard deviation increase in *Log(Intensity1+1)* is associated with a 13.5%, 14.1%, and 15.8% reduction in firms' 1-year, 2-year, and 3-year ahead EPS forecasts (as a fraction of stock prices), respectively.

Given our aforementioned finding on firm profits, these results suggest that analysts correctly revise their earnings expectations of carbon-intensive firms downward. A natural question to ask is whether analyst forecasts are rational or systematically biased based on available information. We run the baseline regression with signed forecast errors as the dependent variable to examine this question. Specifically, we define signed forecast errors as the difference between actual EPS and consensus EPS forecasts, scaled by lagged stock prices. Table IA.7 in the Online Appendix reports the results, with the results for 1- to 3-year ahead errors in EPS forecasts reported in the corresponding columns. We find that the coefficients on *Post*Log(Intensity1+1)* are not statistically significant and economically small for all three forecast horizons, suggesting that analysts are not systematically biased when forecasting the effects of carbon pricing on firms' future earnings.

To the extent that analysts' consensus earnings forecasts are a good proxy for investor expectations of future cash flows, we expect carbon pricing policies to reduce the value of carbon-intensive firms relative to that of low-emission firms. We can even quantify the effect on firm value by assuming a constant annual discount rate of 8% and a constant long-term earnings growth rate of 3% for all firms. Based on the coefficients shown in Table 8, we calculate that a reduction in earnings expectations alone can lead to a 2.17% reduction in market value for a firm whose a *Log(Intensity1+1)* value is one standard deviation higher.

5.2 Carbon pricing, firm-level climate risk exposure, and cost of capital

Recent studies (Bolton and Kacperczyk, 2021) propose the 'carbon premium' hypothesis in relation to financial markets. Asset pricing theory posits that a positive carbon premium arises when more stringent emission regulations are likely to be proposed and implemented as the global climate worsens, leading to a deterioration in the value of carbon-intensive firms, just when climate change matters most to investor welfare. Under such a scenario, carbon-intensive firms are riskier and should earn higher expected returns than low-emission firms. While Bolton and Kacperczyk (2021, 2023) document a significant positive carbon premium in the US and global equity markets, several other studies (Zhang, 2022; Aswani et al., 2023) challenge these findings. In this subsection, we exploit our setting of the enactment of carbon pricing across countries to examine the carbon premium. If the enactment of carbon pricing initiatives increases the riskiness of carbon-intensive firms, the carbon premium should also increase.

To test the effect of carbon pricing initiatives on the carbon premium, we construct proxies for expected returns on debt and equity securities. We use the simple measure of interest expenses over the total amount of debt outstanding as a proxy for the cost of debt. We construct the implied cost of equity following the approach of Easton (2004) to proxy for expected stock returns.[22] We then run the triple difference regression with the cost of debt and equity as the dependent variables. Panel A of Table 9 reports the results. Column (1) shows that the coefficient on *Post*Log(Intensity1+1)* is positive and significant at the 5% level, suggesting that carbon pricing policies lead to an increased cost of debt for carbon-intensive firms. Similarly, column (2) shows that carbon pricing policies also significantly increase the implied cost of equity for carbon-intensive firms. These results are consistent with those of Bolton and Kacperczyk (2021) and Hsu, Li, and Xu (2022), who document a positive carbon premium and pollution premium, respectively, in the US equity market. The coefficient in column (2) suggests that a one standard deviation increase in *Log(Intensity1+1)* leads to a 0.43% (1.9375 * 0.0022) increase in firms' implied cost of equity after carbon pricing initiatives are implemented. The economic effect is non-trivial, as the median implied cost of equity (*r_mpeg*) for our sample is 10.90%.

We further examine whether the increased carbon premium occurs because investors perceive higher transition risk after the adoption of carbon pricing policies. To test this, we examine the effects of carbon pricing initiatives on firm-level climate risk exposure, which is constructed by Sautner et al. (2023) using earnings conference call data. The results are reported in Panel B of Table 9. Column (1) shows that the coefficient on *Post*Log(Intensity1+1)* is positive and significant at the 1% level when the dependent variable is firm-level exposure to climate regulatory risk, supporting our conjecture that the increased carbon premium is likely to be explained by increased exposure to climate regulatory risk. In contrast, column (2) shows that the coefficient on *Post*Log(Intensity1+1)* is not significant and economically small when the outcome variable is firm-level exposure to physical risk. As exposure to physical climate risk is unlikely to be affected by carbon pricing policies in a single

[22] We use the implied cost of equity rather than realised stock returns to proxy for expected returns because Pastor, Stambaugh, and Taylor (2022) show that realised returns are not a good proxy for expected returns when the demand for green assets unexpectedly increases over a short sample period.

jurisdiction, the nonsignificant result serves as a placebo test and suggests that our finding on regulatory risk exposure is not spurious.

5.3 Carbon pricing and firm value

As we find that carbon pricing leads to lower expected future cash flows and higher discount rates for carbon-intensive firms, an immediate implication is that such firms should also experience a reduction in firm value. Our first measure of firm value is Tobin's *q*, defined as the market value of a firm divided by the book value of total assets. The market value of a firm is equal to market capitalisation plus the book value of total assets minus the book value of equity.

We run the same triple difference regression with Tobin's *q* as the dependent variable of interest and report the results in column (1) of Table 10. Consistent with our conjecture, the coefficient on *Post*Log(Intensity1+1)* is indeed negative and significant at the 1% level. In terms of economic effect, a one standard deviation increase in *Log(Intensity1+1)* leads to a 3.47% (1.9375 * 0.0179) reduction in Tobin's *q*. To examine the extent to which the combined effects of earnings expectations and discount rates can explain the change in firm value, we conduct the following back-of-the-envelope calculation. Table 9 shows that a one standard deviation increase in *Log(Intensity1+1)* leads to a 0.43% increase in firms' implied cost of equity, which translates into a 0.51% reduction in firm value.[23] When combined with an estimated 2.17% reduction in firm value due to lower expected cash flows, this finding implies a reduction in firm value of 2.68%. This calculation suggests that the negative effect on firm value can be almost entirely attributed to a higher discount rate and lower expected future cash flows, with the cash flow channel explaining most of the change in firm value.

---

[23] We run a panel regression of Tobin's *q* on the implied cost of equity (*r_mpeg*) and lagged *ROE*, using the full sample of firm-years. The untabulated results show that the coefficient on *r_mpeg* is -1.1923 (t = -20.833), which is our estimated sensitivity of the change in firm value to the change in the implied cost of equity.

We run a complementary test on the effect of carbon pricing on firm value by examining the effect of carbon pricing on contemporaneous stock returns. Both a positive shock to the discount rate and a negative shock to expected cash flows imply that carbon-intensive firms should experience lower realised stock returns after the enactment of carbon pricing policies. We run the triple difference regression with annual stock returns (*Ret_annual*) as the dependent variable. We report the results in column (2) of Table 10. The negative and significant coefficient on *Post*Log(Intensity+1)* is consistent with our prediction that carbon pricing initiatives lead to lower stock returns for carbon-intensive firms relative to low-emission firms. The economic effect on stock returns is slightly smaller than the effect on Tobin's *q*, as a one standard deviation increase in *Log(Intensity1+1)* leads to 2.89% (1.9375 * 0.0149) lower annual stock returns after the enactment of carbon pricing.

5.4 Carbon pricing and real investments

The *q* theory of investment predicts a strong relationship between firms' market value and their investment rates (Hayashi, 1982). As carbon pricing initiatives reduce the value of carbon-intensive firms, we examine how firm investments respond to the enactment of carbon pricing policies. We use multiple measures of real investments, including investment in fixed assets, growth opportunity, and human capital. Following the literature, *CapEx_assets* is computed as capital expenditures divided by the book value of total assets. *R&D_sales* is computed as R&D expenditures divided by total sales. *Employees_sales* is computed as the total number of employees divided by total sales. We run the same triple difference regression with *CapEx_assets*, *R&D_sales*, and *Employees_sales* as the dependent variables and report the results in Panel A of Table 11. The coefficients on *Post*Log(Intensity1+1)* are negative and significant for all three measures of investment. This is consistent with our prediction that as the marginal profits of brown projects decline after the enactment of carbon pricing initiatives, carbon-intensive firms reduce their optimal level of investment relative to low-emission firms.[24]

Another potential reason that carbon-intensive firms cut investment concerns financial constraints, as we show that such firms face higher costs of debt and equity financing and have lower internal cash flows. We test the implications of carbon pricing for firm financial constraints and present the results in Panel B and Panel C of Table 11. Our first prediction of tightened financial constraints is that carbon-intensive firms hold more cash, due to the precautionary savings motive. The dependent variable in column (1) of Panel B is cash holdings, defined as cash and cash equivalents divided by the book value of total assets. The coefficient on *Post*Log(Intensity1+1)* is positive and significant at the 1% level, suggesting that carbon-intensive firms face more binding financial constraints than other firms. Column (2) shows that carbon-intensive firms do not increase leverage, probably because the cost of debt financing is higher for such firms. We further use the cash flow sensitivity of cash measure as a proxy for financial constraints (Almeida et al., 2004) and report the results in Panel C of Table 11. We find that carbon-intensive firms save more cash from their cash flows after the enactment of carbon pricing in their jurisdictions, supporting our conjecture that carbon-intensive firms face tightened financial constraints, due to the regulatory burden of carbon pricing initiatives.

6. Conclusion

Economists have long argued that carbon pricing is the most flexible and cost-effective method to mitigate climate change. A major block to pricing carbon pollution, however, is concerns

[24] Several recent studies document that high-emission firms increase green innovation when facing higher emissions taxes (Brown et al., 2023) or equity price devaluation driven by rising climate awareness (Choi et al., 2023). In untabulated results, we test whether carbon pricing initiatives incentivise high-emission firms to engage more in climate-related innovation. We use the number of climate patents and the ratio of climate patents (the number of climate patents relative to the total number of patents) as proxies for climate innovation. We find a small and statistically nonsignificant effect of carbon pricing initiatives on climate innovation in high-emission firms relative to low-emission firms.

about the associated economic costs. In this paper, we conduct a comprehensive analysis of the impact of carbon pricing on firms' operating performance, market value, and real investments, using a sample of 104,100 firm-year observations covering 16,222 unique firms across 52 countries.

Using the staggered enactment of carbon pricing initiatives across jurisdictions and a triple difference approach, we find a significant reduction in the profitability and market value of carbon-intensive firms relative to low-emission firms after the enactment of carbon pricing. Further analyses show that the reduction in firm profits is driven by both a decrease in sales growth and an increase in operating costs. The reduction in firm value is driven by both an increase in the cost of capital and a decrease in expected future cash flows. Relative to low-emission firms, carbon-intensive firms also cut investments and lay off employees more. Exploiting cross-country heterogeneity, we find a stronger effect of carbon pricing on the profits of firms headquartered in North America and in countries that rely more on fossil fuels for energy.

Overall, our findings uncover the large distributional impacts of carbon pricing policies on individual firms and complement prior studies focusing on the macroeconomic impacts of such policies. The large distributional impacts of carbon pricing policies suggest that targeted fiscal policies could be an effective way not only to reduce the economic costs of carbon pricing on the most affected firms and workers but also to gain public support for such initiatives.

Acknowledgement

Professional English language editing support provided by AsiaEdit (asiaedit.com).

References

Almeida, H., Campello, M., & Weisbach, M. S. (2004). The cash flow sensitivity of cash. *The Journal of Finance*, *59*(4), 1777-1804.

Andersson, J. J. (2019). Carbon taxes and CO2 emissions: Sweden as a case study. *American Economic Journal: Economic Policy*, *11*(4), 1-30.

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

Atilgan, Y., Demirtas, K. O., Edmans, A., & Gunaydin, A. D. (2023). Does the carbon premium reflect risk or mispricing?. *Available at SSRN*.

Bai, J., & Ru, H. (2022). Carbon Emissions Trading and Environmental Protection: International Evidence. *Management Science*, forthcoming.

Baker, A. C., Larcker, D. F., & Wang, C. C. (2022). How much should we trust staggered difference-in-differences estimates?. *Journal of Financial Economics*, *144*(2), 370-395.

Bartram, S. M., Hou, K., & Kim, S. (2022). Real effects of climate policy: Financial constraints and spillovers. *Journal of Financial Economics*, 143(2), 668-696.

Bayer, P., & Aklin, M. (2020). The European Union emissions trading system reduced CO2 emissions despite low prices. *Proceedings of the National Academy of Sciences*, 117(16), 8804-8812.

Ben-David, I., Jang, Y., Kleimeier, S., & Viehs, M. (2021). Exporting pollution: where do multinational firms emit CO2?. *Economic Policy*, *36*(107), 377-437.

Bolton, P., & Kacperczyk, M. (2021). Do investors care about carbon risk?. *Journal of Financial Economics*, 142(2), 517-549.

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

Bolton, P., Lam, A., & Muûls, M. (2023). Do Carbon Prices Affect Stock Prices?. *Available at SSRN 4369925*.

Brown, J. R., Martinsson, G., & Thomann, C. (2022). Can environmental policy encourage technical change? Emissions taxes and R&D investment in polluting firms. *The Review of Financial Studies*, *35*(10), 4518-4560.

Bushnell, J. B., Chong, H., & Mansur, E. T. (2013). Profiting from regulation: Evidence from the European carbon market. *American Economic Journal: Economic Policy*, *5*(4), 78-106.

Cengiz, D., Dube, A., Lindner, A., & Zipperer, B. (2019). The effect of minimum wages on low-wage jobs. *The Quarterly Journal of Economics*, *134*(3), 1405-1454.

Dang, V. A., Gao, N., & Yu, T. (2022). Climate policy risk and corporate financial decisions: Evidence from the NOx budget trading program. *Management Science*, forthcoming.

De Chaisemartin, C., & D'Haultfoeuille, X. (2020). Two-way fixed effects estimators with heterogeneous treatment effects. *American Economic Review*, *110*(9), 2964-96.

de Silva, T., & Tenreyro, S. (2021). Presidential Address 2021 Climate-Change Pledges, Actions, and Outcomes. *Journal of the European Economic Association*, 19(6), 2958-2991.

Dai, R., Duan, R., Liang, H., & Ng, L. (2021). Outsourcing climate change. *European Corporate Governance Institute–Finance Working Paper*, (723).

Duan, T., Li, F. W., & Wen, Q. (2021). Is carbon risk priced in the cross-section of corporate bond returns?. *Journal of Financial and Quantitative Analysis*, forthcoming.

Easton, P. D. (2004). PE ratios, PEG ratios, and estimating the implied expected rate of return on equity capital. *The Accounting Review*, 79(1), 73-95.

Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of Econometrics*, *225*(2), 254-277.

Gugler, K., Szücs, F., & Wiedenhofer, T. (2024). Environmental Policies and directed technological change. *Journal of Environmental Economics and Management*, *124*, 102916.

Hayashi, F. (1982). Tobin's marginal q and average q: A neoclassical interpretation. *Econometrica*, 213-224.

He, G., Wang, S., & Zhang, B. (2020). Watering down environmental regulation in China. *The Quarterly Journal of Economics*, 135(4), 2135-2185.

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

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

Ivanov, I., Kruttli, M. S., & Watugala, S. W. (2023). Banking on carbon: Corporate lending and cap-and-trade policy. *The Review of Financial Studies*, forthcoming.

Känzig, D. R. (2023). The unequal economic consequences of carbon pricing (No. w31221). National Bureau of Economic Research.

Kumar, M., & Purnanandam, A. (2022). Carbon Emissions and Shareholder Value: Causal Evidence from the US Power Utilities. *Available at SSRN 4279945*.

Laeven, L., & Popov, A. (2023). Carbon taxes and the geography of fossil lending. *Journal of International Economics*, *144*, 103797.

Lin, B., & Li, X. (2011). The effect of carbon tax on per capita CO2 emissions. *Energy Policy*, *39*(9), 5137-5146.

Martin, R., De Preux, L. B., & Wagner, U. J. (2014). The impact of a carbon tax on manufacturing: Evidence from microdata. *Journal of Public Economics*, 117, 1-14.

Martinsson, G., Sajtos, L., Strömberg, P., & Thomann, C. (2024). The Effect of Carbon Pricing on Firm Emissions: Evidence from the Swedish CO2 Tax. *The Review of Financial Studies*, forthcoming.

Metcalf, G. E., & Stock, J. H. (2020). Measuring the Macroeconomic Impact of Carbon Taxes. In AEA Papers and Proceedings (Vol. 110, pp. 101-106).

Metcalf, G. E., & Stock, J. H. (2023). The macroeconomic impact of Europe's carbon taxes. *American Economic Journal: Macroeconomics*, 15(3), 265-286.

Millischer, L., Evdokimova, T., & Fernandez, O. (2023). The carrot and the stock: In search of stock-market incentives for decarbonization. *Energy Economics*, *120*, 106615.

Moessner, R. (2022). Effects of carbon pricing on inflation. Working Paper.

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

Pástor, Ľ., Stambaugh, R. F., & Taylor, L. A. (2022). Dissecting green returns. *Journal of Financial Economics*, 146(2), 403-424.

Ramstein, C., Dominioni, G., Ettehad, S., Lam, L., Quant, M., Zhang, J., ... & Trim, I. (2019). State and trends of carbon pricing 2019. The World Bank.

Pedersen, L. H. (2023). Carbon Pricing versus Green Finance. Working Paper.

Ramadorai, T., & Zeni, F. (2024). Climate regulation and emissions abatement: Theory and evidence from firms' disclosures. *Management Science*, forthcoming.

Rennert, K., Errickson, F., Prest, B. C., Rennels, L., Newell, R. G., Pizer, W., ... & Anthoff, D. (2022). Comprehensive evidence implies a higher social cost of CO2. *Nature*, 610(7933), 687-692.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & van Ypserle, J. P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (p. 151). Ipcc.

Sautner, Z., Van Lent, L., Vilkov, G., & Zhang, R. (2023). Firm-level climate change exposure. *The Journal of Finance*, *78*(3), 1449-1498.

Sautner, Z., Van Lent, L., Vilkov, G., & Zhang, R. (2023). Pricing climate change exposure. *Management Science*, forthcoming.

Shapiro, A. F., & Metcalf, G. E. (2023). The macroeconomic effects of a carbon tax to meet the US Paris Agreement target: The role of firm creation and technology Adoption. *Journal of Public Economics*, *218*, 104800.

Stiglitz, J. E. (2019). Addressing climate change through price and non-price interventions. *European Economic Review*, 119, 594-612.

Stern, N. (2008). The economics of climate change. *American Economic Review*, *98*(2), 1-37.

Sun, L., & Abraham, S. (2021). Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. *Journal of Econometrics*, 225(2), 175-199.

Trump, D. J. (2017). Statement by President Trump on the Paris Climate Accord. Washington, DC: White House.

Yamazaki, A. (2017). Jobs and climate policy: Evidence from British Columbia's revenue-neutral carbon tax. *Journal of Environmental Economics and Management*, *83*, 197-216.

Zhang, S. (2022). Carbon premium: Is it there?. *The Journal of Finance*, forthcomin