# The race for carbon pricing amongst firms

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**Abstract**

Although carbon pricing should have a nontrivial impact on environmental performance of firms, prior studies have paid little attention to the type and number of carbon pricing mechanisms (CPMs) that firms adopt simultaneously. In this study, we analyze multiple CPMs within a single framework: carbon trading on compliance markets, carbon tax, and internal carbon pricing. Using a sample of 2,303 CPM-adopting firms, we capture the relative impact of the presence of single and multiple CPMs on firms' environmental performance measured through carbon intensity, energy intensity, and environmental score. The results show that while carbon tax can independently provide significant improvements in environmental performance, carbon trading and internal carbon pricing are ineffective on their own, and can even be detrimental in some cases. There are significant heterogeneities in the effectiveness of CPMs for carbon-intensive sectors versus other sectors and in different regions. Lastly, we provide insights into how environmental innovation and board independence moderate the effect of CPMs on environmental performance.

*Keywords: Carbon pricing mechanisms, carbon markets, carbon tax, internal carbon price, environmental performance*

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# 1 Introduction

In an unprecedented era of climate change, carbon pricing has emerged as one of the key instruments to deliver the goals of the Paris Agreement (Tvinnereim and Mehling, 2018; Stiglitz et al., 2017). In 2015, during the Conference of Parties (COP), around 90 countries expressed their intention to introduce carbon pricing as part of their commitments (Ducret et al., 2016). The number of countries employing a carbon tax and/or a cap-and-trade system is increasing in recent years (Metivier et al., 2018). Even prior to COP21, firms have looked to transcend environmental expectations through the use of better technological infrastructure in order to curb greenhouse gas (GHG) emissions and budget emission allowances under emission trading systems (Kolk et al., 2008). In parallel, the lobbying and advocacy by non-governmental organizations have fueled the disclosures of GHG emissions by firms. Meanwhile, investors and banks have also increasingly become wary of climate risks (Bolton and Kacperczyk, 2021; Venturini, 2022). Therefore, over the years, the prominence of climate management practices has grown in the corporate world (Hoffman, 2005; Lee, 2012). This is partly driven by increased sensitivity to "climate-risk management" as climate change drives companies toward internalizing carbon risks Bolton et al. (2022); Wang et al. (2024).

Carbon pricing is amongst the most widely debated climate management practices employed in response to environmental regulations (Zhu et al., 2022; Green, 2021). By setting a price on each ton of emitted carbon dioxide ($CO_2$) from the business activities, firms bear the additional costs that ultimately reduce their profitability if they are not environmentally conscious. Firms are concerned about carbon pricing regulations negatively impacting their profitability and are thus resorting to reactive or proactive strategies (Fu et al., 2023). Meanwhile, policy makers expect such regulations to stimulate investment in green technology, reduce emissions, and improve environmental performance (Downar et al., 2021). While these effects may occur, the real implications can be more intricate and difficult to capture. Nevertheless, understanding the effectiveness of carbon pricing initiatives is of utmost importance not only for firms and its investors, but also for policy makers.

In this paper, we study the impact of several carbon pricing mechanisms (CPMs) on the firms' environmental performance. Despite the voluminous work on carbon pricing and firm performance, previous studies have always focused either on a single pricing mechanism in isolation or have only investigated macro-level impacts (see, for example, Ren et al., 2022; Liu et al., 2017; Martin et al., 2014; Sterner, 2007). There is little work on how one CPM could potentially be more effective than another or whether the deployment of multiple CPMs could potentially accentuate their effectiveness in firms. We fill this gap in the literature by empirically examining the effect of the adoption of multiple CPMs, i.e., carbon markets trading (CM), carbon tax (CT), and internal carbon pricing (ICP), on environmental performance. To be more precise, this paper contributes to the literature by addressing the following questions: Do CPMs effectively impact environmental performance? Does the adoption of multiple CPMs amplify this impact? We also run supplementary tests to explore heterogeneities in CPMs effectiveness across industries or regions and to identify potential factors that moderate their effectiveness.

There are several empirical challenges that arise when studying the effect of multiple CPMs' adoption on environmental performance. First, there is no single database that tracks the deployment of different CPMs by firms. One of our contributions is the creation of a comprehensive database of a wide range of firms across the globe between 2012 and 2022, including firms operating under emission trading systems (ETSs) from the EU, California, RGGI, Quebec, and New Zealand. We augment this with the information on firms that are subject to carbon tax policies in 25 countries and firms that have started disclosing internal carbon price over the years. Having an international sample allows us to explore and examine whether there are country- or region-specific heterogeneities in the effectiveness of different CPMs. Second, since our initial analyses are conducted using a database of firms that have adopted at least one CPM over the years, endogeneity concerns arise. For example, there may by significant differences in the CPM adopting and non-adopting firms (or a case of self-selection). We tackle this concern by using propensity score matching (PSM) to examine whether there are significant differences in the effectiveness of firms adopting CPMs and those that do not. Third, identifying the relative importance of various CPM adoptions requires that the presence of several CPMs in our sample firms are captured altogether. In other words, studying each CPM adoption separately using a regression framework does not allow for cross-comparison of coefficients of each CPM because systematic differences in samples (or, selection bias) may distort their interpretability. Moreover, alongside the impact of each CPM on environmental performance, the effectiveness of the simultaneous presence of multiple CPMs is also important. We overcome this challenge by coding the simultaneous presence of multiple CPMs in our sample firms over the years and employing a regression framework that can estimate both the relative impact of each CPM on its own and each of their possible combinations.

Using a sample of 2,303 CPM adopting firms, we employ a difference-in-differences approach to compare them to a sample of 1,505 non-CPM adoption firms. In our estimations, that control for firm characteristics as well as industry, country, and year heterogeneities, we find that the CPM adopters have better environmental performance than the non-adopters. This result remains robust even when we employ PSM to identify a comparable non-CPM firm for each CPM adopter. However, more importantly, when we delineate each of the CPMs, our results show that carbon tax (CT) is the only CPM that thrives independently in improving environmental performance across all the three environmental proxies. For the other two CPMs, we observe that both CM and ICP are detrimental to carbon intensity and energy intensity. Moreover, while the presence of different combinations of CPMs does not provide any marginal benefits by reducing carbon intensity, the presence of ICP together with either CT or CM can significantly reduce firms' energy intensity. Put differently, in general, CM and ICP need to be paired in order to be effective. The presence of all three types of CPMs together neither impacts carbon intensity nor energy intensity in firms. However, it does improve overall environmental performance as proxied by the firms' Environmental Score.

Next, we study the differences in how the adoption of CPMs affects carbon-intensive vis-à-vis other sectors. We find that CT is the most consistent CPM when it comes to capturing the improvement in environmental performance across all its three proxies in the carbon-intensive industries. Meanwhile, for non-carbon intensive sectors, when all three CPMs are present in the firms together, they appear to be detrimental to environmental performance. The results also generally confirm that CPM is more effective for carbon intensive industries than others. We also examine the regional heterogeneity in the effectiveness of CPMs. Among North American firms, CT reduces carbon emissions by itself and when present along with CM. For the Asian firms, the presence of CM, and more so the presence of CM with ICP, decreases their employed energy intensity, while the presence of CT with ICP has a negative effect on their $CO_2$ emissions. When all three types of CPMs are present in the firms, they do not have statistically significant impact on environmental performance in any of the regions.

Lastly, we provide some insights into the role of environmental innovation and board independence in making CPMs more effective. The presence of all three types of CPMs does not reflect on environmental performance unless there is an increase in environmental innovation and board independence.

By showing how CPMs impact the firms' environmental performance, our results have important implications for multiple knowledge areas including finance, accounting, environmental economics, and, to some extent, even business ethics. We contribute to these strands of literature in several ways. First, prior studies have highlighted the impact of carbon emissions and environmental performance on firm valuation (Bolton and Kacperczyk, 2021; Oestreich and Tsiakas, 2015; Matsumura et al., 2014; Zhang et al., 2024), cost of debt (Bolton et al., 2022; Jung et al., 2018; Han et al., 2024), and capital structure (Nguyen and Phan, 2020). We take a step back and study how different decarbonization initiatives represented by CPMs can affect carbon emissions and environmental performance. Second, and related, a recent strand of literature has examined the effectiveness of CPMs. For instance, Zhu et al. (2022), Liu et al. (2017), and Martin et al. (2014) study the environmental performance of firms when they adopt ICP, CM, and CT, respectively. We contribute to this literature by investigating how these three different CPMs together impact environmental performance. More precisely, by studying three different types of CPMs within a single framework, this paper identifies their individual and combined effects on environmental performance in tandem, given that the firms can adopt these in parallel. This means that we are able to identify those CPMs—individually or in combinations—that are the main drivers of environmental performance. Third, carbon emission regulations and their effectiveness is a widely debated topic among scholars (Green, 2021; Tvinnereim and Mehling, 2018; Bruvoll and Larsen, 2004; Ma and Li, 2024). However, much of the literature has focused largely on the EU (e.g., Dechezleprêtre et al., 2018; Liu et al., 2017) or China (e.g., Shen et al., 2020; Zhang et al., 2024) with very little evidence exploring global dynamics. We contribute to this literature by studying a large international sample of firms and providing insights on heterogeneities in the effectiveness of different CPMs.

This study also has important policy implications, as it provides insights into the optimal number of carbon pricing policies for achieving environmental sustainability goals. First, this study can help policy makers obtain an overview of the microlevel impacts of CPMs. Second, it calls for more guidance and standardization of CPMs at the global level in light of the disparities observed in environmental outcomes at the regional level.

The rest of the paper is organized as follows. Section 2 outlines the theoretical background of this research by reviewing the relevant literature. Section 3 presents the data and methodology used in the study, and Section 4 analyses the results and discusses the main findings. Finally, Section 5 concludes the paper.

# 2 Literature Review

Carbon pricing is used as a disincentivizing mechanism to encourage firms to curb their emissions levels and stimulate investment and research in low carbon technologies (Andersson, 2019; Best et al., 2020). This section provides an overview of the theoretical motivation for firms' adoption of CPMs and elaborates on the relationship between carbon pricing and firms' environmental performance.

## 2.1 Theoretical Foundation

According to Pinker (2021), environmental problems can be solved given the right knowledge and the proper use thereof. While climate risk remains a central focus of international debates, it is necessary to investigate the costs related to such risk (Ehlers et al., 2022; Stroebel and Wurgler, 2021; Jung et al., 2018). This study is grounded in the Porter hypothesis proposed in Porter and Van der Linde (1995), which challenges the conventional view and argues that well-designed regulations can lead to improvements in environmental quality without having any negative effects on economic performance, thus resulting in a 'win-win' situation. Thus, positive effects can be observed with regard to both environment and firm performance based on the innovation incentive provided by the regulation in question (Ambec et al., 2020). In the past, the Porter hypothesis has been studied extensively and has reinvigorated policy debates; furthermore, different versions of the hypothesis have been proposed (Zhu et al., 2021; Zhang et al., 2024). Findings regarding the impacts of environmental regulations on innovation, competitiveness, or firm performance, however, have been mixed (Degryse et al., 2023; Guo et al., 2023; Chakraborty and Chatterjee, 2017). Some studies have argued that environmental regulation positively influences productivity levels (see Yang et al., 2012; Yin and Cao, 2024), while others have found that it results in a decline in productivity (e.g., Greenstone et al., 2012). When considering these inconsistent findings, it should be remembered that Porter and Van der Linde (1995) emphasized the importance of well-designed regulatory instruments for the achievement of innovation offsets.

To enable firms to achieve their impending emission reduction goals, carbon pricing acts as a means of cost externalization for firms (Bolton et al., 2022; Nguyen and Phan, 2020). In recent years, some studies related to carbon pricing have explored the Porter hypothesis (e.g., Jin et al., 2022; Ren et al., 2022). Essentially, "the mechanism of tradable emission permits as a popular market-oriented regulation system is more promising in efficiently controlling pollution-reduction than traditional command-control instruments" Jin et al. (2022). However, evidence drawn from similar practices in emerging markets has also shown that these market-oriented systems are not always effective (Tu and Shen, 2015). In this study, we adopt a global perspective and explore the effectiveness of the adoption of different types of carbon pricing interventions or CPMs.

## 2.2 Carbon Pricing Mechanisms

First, as a carbon pricing tool, the cap-and-trade system uses the total 'cap' to attain environmental goals and allows 'trade' to achieve effective scheduling through market regulation. The cap-and-trade system stipulates a certain quantity of emissions that is set by the government, which is also known as the upper limit. Firms are allowed to trade their allowances on the market, but each year, they must surrender a number of allowances equivalent to their emissions limit. Carbon emissions trading systems (ETSs) were introduced after the emergence of the Kyoto Protocol and are considered to be critical drivers of climate ambitions (Ren et al., 2022). The ultimate goal of an ETS is to allow an environmental target to be achieved at minimal costs while incentivizing decarbonization and innovation among firms. To date, numerous countries have adopted this mechanism, including the United States, various countries in the European Union, Japan, Australia, New Zealand, Canada and China (Calel and Dechezleprêtre, 2016). The EU Emission Trading System (EU ETS) is the largest trading system for emissions, including more than 11,000 firms across 30 countries. Following the COVID-19 pandemic, the European Emission Allowances (EUA) price dropped to approximately €10 and then increased to more than €90 in early 2022 (Ohlendorf et al., 2022). Through this system, firms can trade their excess emissions with other enterprises that can maintain their own emissions below the cap level. Thus, such emission permits have become a valuable resource that can significantly affect productivity and environmental performance (Du et al., 2013, 2016).

The second type of carbon pricing, carbon taxes, is more direct; such taxes represent surcharges on fuel or energy use. Governments often face a dilemma with regard to generating appropriate carbon tax legislation to reduce emissions and economic impacts (Varsei et al., 2014). Most governments have chosen to implement progressive carbon taxation, which starts with a low carbon price and tends to increase over time until the target is met. The Swedish government adopted a concave carbon tax scheme in 1990, the French government implemented a convex form of carbon tax in 2014, and the Canadian government stipulated a linear carbon tax scheme in 2018. Scholars have also advocated for carbon tax regulation instead of the cap-and-trade system given that the former approach is easier to implement (Avi-Yonah and Uhlmann, 2009; Inglis and Laffer, 2008). Carbon tax schemes have also been subject to certain criticisms. Hoel (1996) highlighted the fact that carbon-intensive tradable sectors should feature lower carbon taxes since the tax relocates $CO_2$ emissions to countries that lack a carbon tax. There is also an ongoing debate regarding whether carbon taxes should differ across industry sectors given their common or distinctive characteristics (Touboulic et al., 2014).

The third type of CPM is 'internal carbon pricing'. Internal carbon pricing is voluntarily adopted by companies in two major forms, notably *shadow carbon pricing* and *internal carbon tax pricing*. The year 2020 witnessed exponential growth in net-zero commitments by 1,541 companies across 127 countries as well as a 20% increase in the adoption of carbon pricing (World-Bank, 2021). As such, internal carbon pricing can play a role by sending a price signal that can incentivize low carbon actions and prevent firms from locking in more fossil fuel-intensive investments (Popp et al., 2010; Nordhaus, 2014). The rapidly increasing popularity of internal carbon pricing is evident in the fact that the largest 500 companies worldwide have either already adopted or soon intend to adopt this instrument.

This review indicates that firms can benefit from the efficient and effective use of CPMs to achieve carbon emission reduction and improve their environmental performance. Despite the fact that carbon markets and emission trading systems are known to achieve emission reductions at lower cost than carbon taxes (Elkins and Baker, 2001), it is now common for firms to adopt multiple carbon pricing policies (Wang et al., 2019).

## 2.3 Firms' Environmental Performance and Carbon Pricing

The presence of carbon risks and carbon performance have been a central focus of investors in recent years (Kreuzer and Priberny, 2022; Azar et al., 2021; Bolton and Kacperczyk, 2021). Economic theory has further indicated that the market failures resulting from climate change must be addressed using a dedicated policy instrument (Goulder and Parry, 2020). The traditional view is that carbon pricing regulations should increase the cost burden faced by firms, thus motivating them to transition to activities associated with lower emissions and to improve environmental and social welfare (Calvet et al., 2022). However, such a view is inconsistent with the classic economic theory that posits that firms always aim to minimize costs and that such regulations increase their costs (Smith and Walsh, 2000; Palmer et al., 1995). As such, carbon pricing policies take various forms, as discussed above. Researchers have reached a broad consensus that carbon pricing can be a fundamental instrument in the fight against climate change. Sterner (2007) found that fuel taxes have contributed to emission reductions in Europe and Japan. Similar results have been reported regarding carbon taxes in other countries (e.g., Bruvoll and Larsen, 2004). Han et al. (2024) simulated 16 carbon tax scenarios in Chinese commercial banks and found that a carbon tax significantly increases bank credit losses, with credit losses escalating exponentially as tax rates increase. The cap-and-trade system has also been effective in reducing emissions over time (Martin et al., 2016). Thus, as in the case of national carbon pricing policies, the question of whether such an effect is evident at the corporate level as well is worth investigating (Ma and Li, 2024). Internal carbon pricing can also help reduce emissions by monetizing this process, facilitating internal dialogs concerning progress and raising awareness (Zhu et al., 2022).

The connections between ETSs and firm performance have been explored in the literature from different perspectives: technological innovation (Rogge et al., 2011), emission reductions (Anderson and Di Maria, 2011; Zhang et al., 2024), and financial performance (Wu and Wang, 2022; Downar et al., 2021; Oestreich and Tsiakas, 2015). Previous studies have found that ETSs in the EU have triggered low carbon investments only to a modest degree due to the low price established for EUA in the early phases (Calel and Dechezleprêtre, 2016). Fullerton and Metcalf (2002) studied the cap-and-trade system in the presence of a monopoly, and their results indicated a reduction in welfare gains from environmental restrictions. Chen et al. (2024) found that ETS could entail the twofold benefits of green development efficiency and regional carbon equality.

Krass et al. (2013) investigated the impact of carbon tax regulation using a static modeling approach and found that firms react to an increase in taxes in a manner that motivates them to transition to low-carbon technology. Shen et al. (2021) also stipulated that environmental taxes lead to increased investments in green technology and supply chains. Shittu and Baker (2009) studied the influence of a carbon tax on optimal investments in energy research and development and highlighted the fact that the elasticity substitution between fossil and nonfossil energy outputs is positively correlated with investment allocation. Previous studies have thus revealed that a carbon tax positively impacts low carbon investment and environmental performance. Letmathe and Balakrishnan (2005) reviewed the production mix and production quantities under conditions of carbon taxes and emission trading. Li et al. (2017) assessed the impacts of single versus multiple carbon policies in the transport sector and found that an extended model featuring carbon policies is more beneficial for emission reduction. Similarly, Drake et al. (2016) found that firms facing both cap-and-trade and carbon taxes choose to maximize profit in the second stage of the regulations. Jin et al. (2014) studied the impacts of carbon policies (both cap-and-trade and carbon tax) on the supply chain designs and logistics of a major retailer. Bowen (2011) and Baranzini et al. (2017) found that a carbon tax encourages investment in innovative as well as low-carbon-emitting technologies. However, Faber and Frenken (2009) and Hall and Helmers (2013) claimed that a carbon tax can have a negative or nonsignificant impact on environmental performance due to the 'double externality problem'. Market imperfections impede the promotion of green activities through carbon pricing. Feichtinger et al. (2022) highlighted the fact that a carbon tax can lead to a win-win solution with regard to both profits and social welfare through a dynamic differential game.

Another stream of literature has focused on comparing the performance of CPMs. Drake et al. (2016) argued that a firm can obtain greater profits under a cap-and-trade system than under a carbon tax due to price uncertainty and operational flexibility. Drake (2018) also explored the challenge of carbon leakage under a carbon tax and found that this regulation still effectively reduced emissions. Chang et al. (2015) examined three different carbon emission regulations (mandatory carbon emissions, carbon taxes, and cap-and-trade) and developed two profit-maximization models for the manufacturing industry. These authors found that the carbon tax was more effective at reducing emissions than other policies.

The papers mentioned above focused on carbon pricing regulations as mechanisms that can induce firms to make more informed operational decisions. This paper is aligned with this stream of literature and contributes by drawing attention to an individual firm's environmental responses to regulations.

## 2.4 Measures of Environmental Performance

Researchers and policy makers have given renewed attention to measures of environmental performance in the context of carbon pricing. An emerging trend involves measuring emissions through carbon intensity rather than examining absolute emissions in isolation (Pedersen et al., 2021; Matsumura et al., 2014). Firms in major polluting industries are more likely to exhibit different carbon intensities. A study conducted by Fu et al. (2023) demonstrated that emission asymmetries can play a significant role in a firm's decision to improve its environmental performance. Martin et al. (2014) assessed the impact of a carbon tax on energy intensity and electricity use by manufacturing firms in the UK. Dussaux (2020) evaluated the relationship between carbon tax and environmental performance by employing energy use, electricity use, fossil fuel use and $CO_2$ emissions as proxies. Shen et al. (2020) studied the impacts of trading and carbon emissions by Chinese firms by using the total amount of carbon emissions as a proxy. Other sustainability studies have proposed diverse variables as proxies for environmental performance. For example, Li and Lu (2016) found that environmental practices such as toxic releases, the discharge of polluted water, noncompliance with environmental statutes, the firm's environmental rating and environmental capital expenditure can be used as representatives of environmental performance. Zhu et al. (2022), investigating the impact of internal carbon pricing on environmental performance, identified firms' total carbon emissions with scope 1 and scope 2 emissions and thus calculated the firms' carbon intensity. Motivated by the empirical review by Dragomir (2018), these authors used metric tons of carbon emissions per full-time equivalent employee (employee intensity) and metric tons of carbon emissions per increment of revenue (revenue intensity) to avoid problems resulting from firms that grow or contract shifts which are often accompanied by changes in carbon emissions.

As discussed above, due to the emergence of increasingly strict carbon pricing regulations, it is crucial to study firms' environmental performance in these circumstances. Scholars have been broadly studying how carbon policies may affect industry competitiveness in the face of rising costs and foreign imports. Attention has been given to policies and jurisdictions rather than to microlevel environmental outcomes. Our paper specifically aims to fill all these research gaps.

# 3 Research Design

## 3.1 Sample and Data

Carbon pricing has received increasing interest in recent years for the following reasons. Companies need robust policies to survive in a decarbonized economy and thereby use internal carbon pricing to mitigate risk. Second, the interest of investors in assessing the risks associated with stranded assets in a pivotal climate policy environment is increasing. Third, governments worldwide are imposing costs on $CO_2$ emissions to mitigate climate change. The World Bank's 2021 report claimed that more than 64 CPMs involving ETSs and carbon taxes are presently in operation or are soon scheduled for implementation. In this paper, we study the adoption of CPMs as of 2012 for the following reasons. First, most of the carbon markets were launched in that year (especially California, Quebec, and Chinese pilot carbon markets). Second, the coverage of data on the adoption of internal carbon pricing by firms on LSEG (formerly Refinitiv) was not optimal before 2012. Thus, by opting to begin our sample period in 2012, we ensured that the adoption of all three CPMs are well-represented in our study.

### 3.1.1 Firms Trading in Carbon Markets

Previous studies have been skewed toward the EU ETS. This study expands the literature to account for firms operating under diverse ETSs, such as the ETSs associated with the RGGI, California, Quebec and New Zealand (see Appendix A for further details). Unfortunately, data regarding Asian carbon markets, notably the Chinese pilot ETS and the South Korean market, were not available when this study was conducted. The list of firms operating under the aforementioned ETSs was retrieved from the corresponding registries. With regard to the EU ETS, approximately 6,000 firms were identified on LSEG, while 201 firms were identified for the New Zealand ETS, 434 for the Californian ETS, 519 for the RGGI and 123 for the Quebec ETS. Given that most of these firms are private companies, access to their environmental data is restricted. After retrieving the data, 381 firms trading on compliance carbon markets were included in this study.

### 3.1.2 Firms Subject to Carbon Taxes

The term carbon tax refers to all taxes for which the rate is explicitly linked to the carbon content of the fuel used as well as cases in which a tax is levied directly on GHG emissions. The term carbon tax is similarly used for taxes that apply to GHGs other than $CO_2$ (Dussaux, 2020). The pricing dashboard provided by the World Bank reports that approximately 27 countries have adopted carbon tax policies thus far.[1] This study considers firms operating globally that are subject to carbon taxes. Firms that are energy intensive and that operate in the manufacturing sector are included in the sample, an approach which is in line with the previous studies by Dussaux (2020) and Martin et al. (2014). The LSEG screener function is used to filter and identify the firms from each country. Approximately 1,505 firms that are subject to CT are included in the sample.

#### 3.1.3 Firms Adopting Internal Carbon Pricing

World-Bank (2021) reported that nearly half of the largest 500 companies worldwide have an internal carbon pricing policy or intend to adopt such a policy in the upcoming two years. The latest Carbon Disclosure Project (CDP) report in 2020 indicated a 43% increase in the number of companies adopting internal carbon pricing within two years. The report also highlighted three main motivations for adopting internal carbon pricing: to drive low-carbon investment, to promote energy efficiency and to change internal behavior. LSEG collects data regarding the adoption of internal carbon prices. We retrieved these data using the LSEG screener function, and 628 companies with ICP are included in the sample.

### 3.2 Variables

#### 3.2.1 Carbon Pricing Mechanism (CPM)

The carbon pricing variables, which are categorized into emission trading systems, carbon taxes and internal carbon pricing, are implemented as dummy variables that are set at 1 if firm has adopted any one of these CPMs; otherwise, they are set at 0. Some firms are subject to several pricing mechanisms; accordingly, these individual dummy variables are

[1] Appendix B lists the countries, the implementation year, and the scope of the tax.

Table 1: Adoption of Carbon Pricing Mechanisms (CPMs)

| **#CPMs Adopted =** | Only One | Only Two | All Three | Total |
|---|---|---|---|---|
| CM | 274 | | | |
| CT | 1278 | | | |
| ICP | 269 | | | |
| CM∩CT | | 149 | | |
| CM∩ICP | | 167 | | |
| CT∩ICP | | 89 | | |
| CM∩CT∩ICP | | | 77 | |
| Full CPM Sample | | | | 2,303 |

The table presents the number of firms and their distributions with regard to the adoption of carbon pricing mechanisms. CM represents trading on carbon markets, CT indicates firms that are subject to a carbon tax and ICP refers to firms that have adopted internal carbon pricing.

not mutually exclusive. Firms can also deliberately adopt multiple CPMs simultaneously. As shown in Table 1, our full sample comprises a total of 2,303 firms. All the firms in this sample have adopted at least one type of CPM. All the potential combinations of CPMs (i.e., CM∩CT, CM∩ICP, CT∩ICP, and CM∩CT∩ICP) have also been mapped.

### 3.2.2 Environmental Performance Variables

Based on the extensive literature review presented in Section 2.4, the most frequently used environmental performance measures are Carbon Intensity and Energy Intensity (Mariani et al., 2024). Given that this study focuses on firms located in more than sixteen countries, insufficient data is available to explore other measures of environmental performance. Carbon Intensity is defined as the ratio of carbon emissions (in thousands of tons) over sales. The data were retrieved from LSEG, which reports the relationship of total $CO_2$ equivalent emissions to revenues (USD) in millions. Energy Intensity is often measured in terms of the ratio of total energy use over output. In firm-level studies, expenditure on energy is often used when actual units of energy are not available. LSEG calculates the Energy Intensity based on the relationship of total energy use to revenues (USD). Since environmental performance can be driven by several other strategies implemented within the firm, it is crucial to consider those elements. Thus, to obtain a broader perspective on environmental performance beyond the level of carbon emission and energy consumption, we also include the Environmental Score from LSEG in our analyses. By seeking to investigate the impact of CPMs on multiple proxies of environmental performance, i.e., carbon emissions, energy intensity, and overall environmental score, we believe that we can provide insights on the effectiveness on CPMs from multiple perspectives while also shedding more light on their policy implications.

### 3.2.3 Control Variables

We included all important firm characteristics as control variables. Guo et al. (2019) stipulated that the larger a firm is, the more energy it consumes; therefore, its carbon emissions are also relatively high. Firm size (Size) is the natural logarithm of the firm's total assets at the end of the fiscal year. Firm age (Age) is the number of years since the firm was founded. Governance factors influencing corporate decisions, such as asset liability ratio (Leverage) and board members' independence (Board), are also included (Kim et al., 2020). Huang et al. (2017) and (Guo et al., 2023) found that technological factors such as research and development can have spillover effects on the level of energy consumed and carbon emissions. The Environmental Innovation Score from LSEG is included as a proxy for technological factors.

## 3.3 Descriptive Statistics

To ensure continuity in the data, the longest continuous data concerning the 2,303 CPM-adopting firms from 2012 to 2022 are considered. Table 2 presents the descriptive statistics of all the main variables and Table 3 presents their correlations. The independent variables largely exhibit weak correlations.

Table 2: Descriptive Statistics

| **Variable** | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| *Dependent Variables* | | | | |
| Carbon Intensity | 2.408 | 1.132 | 1.125 | 5.632 |
| Energy Intensity | 2.702 | 1.546 | 1.723 | 8.195 |
| Env. Score | 3.769 | 3.570 | 1.000 | 12.000 |
| *Independent Variables* | | | | |
| CPM | 0.604 | 0.488 | 0.000 | 1.000 |
| CM | 0.208 | 0.406 | 0.000 | 1.000 |
| CT | 0.727 | 0.445 | 0.000 | 1.000 |
| ICP | 0.130 | 0.336 | 0.000 | 1.000 |
| CM∩CT | 0.026 | 0.159 | 0.000 | 1.000 |
| CM∩ICP | 0.036 | 0.187 | 0.000 | 1.000 |
| CT∩ICP | 0.034 | 0.182 | 0.000 | 1.000 |
| CM∩CT∩ICP | 0.030 | 0.170 | 0.000 | 1.000 |
| *Control Variables* | | | | |
| Size | 9.281 | 2.393 | 0.000 | 12.573 |
| Growth | 9.356 | 3.322 | 1.000 | 11.758 |
| Leverage | 0.142 | 0.157 | 0.000 | 2.361 |
| Age | 38 | 34.788 | 0 | 190 |
| Innovation | 30.64 | 34.425 | 0.000 | 99.89 |
| Board | 38.51 | 33.99 | 0.000 | 100.00 |

Table 2 presents the descriptive statistics for the variables used in the main analyses.

Table 3: Correlation Matrix

| | [1] | [2] | [3] | [4] | [5] | [6] | [7] | [8] | [9] | [10] | [11] | [12] | [13] | [14] | [15] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Carbon Intensity [1] | 1 | | | | | | | | | | | | | | |
| Energy Intensity [2] | 0.012 | 1 | | | | | | | | | | | | | |
| Env. Score [3] | 0.044 | 0.031 | 1 | | | | | | | | | | | | |
| CM [4] | 0.019 | 0.04 | 0.007 | 1 | | | | | | | | | | | |
| CT [5] | -0.017 | -0.014 | 0.023 | 0.006 | 1 | | | | | | | | | | |
| ICP [6] | 0.019 | 0.036 | 0.025 | -0.012 | 0.001 | 1 | | | | | | | | | |
| CM∩CT [7] | 0.012 | -0.007 | -0.004 | 0.319 | 0.008 | -0.047 | 1 | | | | | | | | |
| CM∩ICP [8] | 0.006 | 0.009 | 0.015 | 0.379 | 0.017 | 0.013 | -0.032 | 1 | | | | | | | |
| CT∩ICP [9] | 0.003 | -0.015 | -0.003 | -0.097 | 0.007 | -0.033 | -0.031 | -0.037 | 1 | | | | | | |
| CM∩CT∩ICP [10] | 0.04 | 0.005 | 0.018 | -0.017 | 0.018 | -0.018 | -0.005 | 0.031 | 0.013 | 1 | | | | | |
| Age [11] | 0.017 | 0.125 | 0.039 | -0.022 | -0.001 | -0.003 | -0.016 | -0.01 | 0.089 | 0.03 | 1 | | | | |
| Size [12] | -0.003 | 0.254 | -0.023 | 0.016 | -0.028 | 0.006 | -0.022 | 0.021 | 0.073 | 0.003 | 0.199 | 1 | | | |
| Leverage [13] | 0.01 | 0.288 | 0.067 | 0.052 | -0.013 | 0.049 | 0.024 | 0.011 | -0.018 | -0.016 | -0.04 | 0.249 | 1 | | |
| Innovation [14] | -0.005 | 0.136 | 0.007 | 0.037 | -0.05 | -0.005 | -0.016 | 0.041 | 0.115 | 0.009 | 0.224 | 0.353 | 0.066 | 1 | |
| Board [15] | -0.015 | 0.167 | -0.021 | 0.099 | -0.021 | 0.019 | -0.022 | 0.035 | -0.021 | -0.042 | 0.069 | 0.374 | 0.18 | 0.408 | 1 |

Table 3 reports the correlation coefficients for the different dependent and independent variables. Energy Intensity and Carbon Intensity are log transformed. Environmental Score is drawn from the firm's environmental, social, and governance (ESG) ratings reported by LSEG.

## 3.4 Empirical Methodology

We first examine the ability of CPMs to improve firms' environmental performance using a difference-in-differences (DiD) approach with a regression that includes industry ($\Gamma_j$), country ($\Lambda_k$), and year fixed effects ($\tau_t$) to predict environmental performance. We start with estimations that consider each of our three CPMs in isolation as follows:

$$EP_{i,t} = \alpha_0 + \beta_0 CPM_{i,t} + X_{i,t} + \Gamma_j + \Lambda_k + \tau_t + \epsilon_{i,t} \tag{3.1}$$

where $EP$ represents the firms' environmental performance as measured in terms of Carbon Intensity, Energy Intensity, and Environmental Score. The presence of at least one carbon pricing mechanism for each firm $i$ in year $t$ is represented by $CPM$ if the firm trades on carbon markets, is subject to a carbon tax, or has implemented internal carbon pricing. $X_{i,t}$ is an array of firm-level controls that include size, age, green innovation, and environmental rating. The variable $CPM$ captures both a) the difference between the treatment (CPM adopters) and control (CPM-nonadopters) firms and b) the difference before and after CPM adoption.

Next, we explore the abilities of each of the different CPMs both in isolation and in combination by replicating the empirical model in Equation (3.1). We start with estimations that consider each of our three CPMs in isolation:

$$EP_{i,t} = \alpha_1 + \beta_1 CM_{i,t} + X_{i,t} + \Gamma_j + \Lambda_k + \tau_t + \epsilon_{i,t} \tag{3.2a}$$

$$EP_{i,t} = \alpha_2 + \beta_2 CT_{i,t} + X_{i,t} + \Gamma_j + \Lambda_k + \tau_t + \epsilon_{i,t} \tag{3.2b}$$

$$EP_{i,t} = \alpha_3 + \beta_3 ICP_{i,t} + X_{i,t} + \Gamma_j + \Lambda_k + \tau_t + \epsilon_{i,t} \tag{3.2c}$$

where environmental performance ($EP_{i,t}$) and firm-specific controls ($X_{i,t}$) are the same as defined in Equation (3.1); however, the three different CPMs within each firm $i$ in year $t$ are represented by $CM$ for firms trading on carbon markets, $CT$ for firms that are subject to a carbon tax, and $ICP$ for firms that have implemented internal carbon pricing.

We further examine the impact of the presence of more than one CPM on environmental performance. The following models are used to explore the joint effects of various possible combinations of CPMs coexisting within a firm:

$$EP_{I,t} = \alpha_4 + \beta_4(CM \cap CT)_{i,t} + X_{i,t} + \Gamma_j + \Lambda_k + \tau_t + \epsilon_{i,t} \tag{3.3a}$$

$$EP_{i,t} = \alpha_5 + \beta_5(CM \cap ICP)_{i,t} + X_{i,t} + \Gamma_j + \Lambda_k + \tau_t + \epsilon_{i,t} \tag{3.3b}$$

$$EP_{i,t} = \alpha_6 + \beta_6(CT \cap ICP)_{i,t} + X_{i,t} + \Gamma_j + \Lambda_k + \tau_t + \epsilon_{i,t} \tag{3.3c}$$

$$EP_{i,t} = \alpha_7 + \beta_7(CM \cap CT \cap ICP)_{i,t} + X_{i,t} + \Gamma_j + \Lambda_k + \tau_t + \epsilon_{i,t} \tag{3.3d}$$

where $CM \cap CT$, $CM \cap ICP$, and $CT \cap ICP$ represent firms in which any of the two CPMs coexist, while the term $CM \cap CT \cap ICP$ captures cases in which all three mechanisms exist in unison. The other aspects of this empirical specification are similar to those shown in Equation (3.1) and include firm controls $X_{i,t}$, industry fixed effects ($\Gamma_j$) and year fixed effects ($\tau_t$).

Finally, we run a horse race regression to determine in the context of a single framework whether the benefits of the existence of one or multiple CPMs outweigh the benefits of other possibilities. This task is accomplished using the following empirical specification:

$$\begin{aligned} EP_{i,t} =& \alpha + \beta_1 CM_{i,t} + \beta_2 CT_{i,t} + \beta_3 ICP_{i,t} \\ & + \beta_4(CM \cap CT)_{i,t} + \beta_5(CM \cap ICP)_{i,t} + \beta_6(CT \cap ICP)_{i,t} \\ & + \beta_7(CM \cap CT \cap ICP)_{i,t} + X_{i,t} + \Gamma_j + \Lambda_k + \tau_t + \epsilon_{i,t} \end{aligned} \tag{3.4}$$

# 4 Empirical Findings and Discussion

## 4.1 Carbon Pricing Mechanisms and Environmental Performance

Environmental performance is subject to diverse strategies; hence, it is important to determine whether the presence of CPMs is relevant. This is carried out through a treatment group and a control group. The treatment group comprised of firms that have adopted at least one CPM. A control group featuring firms that have not adopted any CPM is then added. The control group was constructed by extracting data regarding firms in countries featuring no carbon regulations (a cap-and-trade system or carbon tax) and that have also not implemented internal carbon pricing. Table 4 confirms that carbon pricing does impact environmental performance. The presence of at least one CPM in a firm seems to improve Carbon Intensity and the firm's Environmental Score significantly. However, insignificant results were observed with regard to Energy Intensity.

#### 4.1.1 Propensity Score Matching (PSM)

The propensity score matching (PSM) method was used to address the endogeneity concern regarding the relationship between CPMs and environmental performance. PSM was used to explore the balance between the treatment (firms adopting carbon pricing) and control groups (firms that do not adopt carbon pricing) based on their propensity scores. The matching was performed based on the size and leverage of the firms. The matching algorithm identified 1,505 pairs in the treatment and control groups. Table 5 presents the quality of the matching by highlighting the fact that no statistically significant differences between the two groups were observed with regard to any important firm characteristics.

Table 6 reports the regression results based on the PSM sample, confirming that a firm with at least one CPM is likely to experience an improvement in environmental performance with regard to Carbon Intensity and Environmental Score.

#### 4.1.2 Disentangling the Importance of Different CPMs

Tables 7, 8 and 9 present the results drawn from the cross-sectional regressions using three different measures of environmental performance. The first three models (1-3) show the regressions based on the adoption of a single CPM: model (1) represents firms only

Table 4: Impact of Carbon Pricing Mechanism on Environmental Performance

| | Carbon Intensity | Energy Intensity | Env. Score |
|---|---|---|---|
| CPM | $-0.256^{***}$ | $-0.315$ | $2.460^{***}$ |
| | (0.217) | (0.232) | (0.499) |
| Age | $0.001^{***}$ | $0.001^{***}$ | $0.001^{**}$ |
| | (0.000) | (0.000) | (0.000) |
| Leverage | $0.253^{***}$ | $1.044^{***}$ | $-0.149^{*}$ |
| | (0.034) | (0.037) | (0.079) |
| Innovation | $0.003^{***}$ | $0.006^{***}$ | $-0.008^{***}$ |
| | (0.000) | (0.000) | (0.000) |
| Size | $-0.001$ | $0.028^{***}$ | $0.026^{***}$ |
| | (0.003) | (0.003) | (0.006) |
| Board | $0.004^{***}$ | $0.010^{***}$ | $0.017^{***}$ |
| | (0.000) | (0.000) | (0.000) |
| Year fixed effect | Yes | Yes | Yes |
| Industry fixed effect | Yes | Yes | Yes |
| Country fixed effect | Yes | Yes | Yes |
| $R^2$ | 0.218 | 0.440 | 0.088 |
| Adj. $R^2$ | 0.214 | 0.438 | 0.084 |
| Num. obs. | 41888 | 41888 | 41888 |

Table 4 presents the results of the differences-in-differences analyses with environmental performance variables included as dependent variables. The sample comprises of all firms in the treatment and control groups. $^{***}$, $^{**}$ and $^{*}$ indicate $p$-values of $< 0.01$, $< 0.05$ and $< 0.1$, respectively.

Table 5: Differences in firm characteristics after PSM

| Variables | Treatment ($N = 1,505$) | Control ($N = 1,505$) | Difference | t-statistics |
|---|---|---|---|---|
| Carbon Intensity | 1.304 | 0.975 | 0.329 | (-0.724) |
| Energy Intensity | 1.699 | 1.827 | 0.128 | (1.575) |
| Env. Score | 3.539 | 4.289 | 0.750 | (1.070) |
| Size | 9.338 | 9.487 | 0.149 | (-1.620) |
| Age | 35.789 | 39.682 | 3.893 | (-1.110) |
| Leverage | 0.230 | 0.160 | 0.07 | (-0.760) |
| Innovation | 33.062 | 29.218 | 3.844 | (1.050) |
| Board | 37.14 | 38.16 | 1.02 | (0.280) |

Table 5 presents the statistics pertaining to the propensity score matching (PSM) analyses. ***, ** and * indicate $p$-values of $< 0.01$, $< 0.05$ and $< 0.1$, respectively.

Table 6: Regression results on the PSM sample

| | Carbon Intensity | Energy Intensity | Env. Score |
|---|---|---|---|
| CPM | $-0.032^{***}$ | 0.003 | $0.153^{***}$ |
| | (0.009) | (0.013) | (0.024) |
| Age | $0.002^{***}$ | $0.003^{***}$ | $-0.002^{***}$ |
| | (0.000) | (0.000) | (0.000) |
| Leverage | $0.388^{***}$ | $0.438^{***}$ | 0.105 |
| | (0.032) | (0.047) | (0.084) |
| Innovation | $0.008^{***}$ | $0.013^{***}$ | $-0.026^{***}$ |
| | (0.000) | (0.000) | (0.000) |
| Size | $0.022^{***}$ | $0.037^{***}$ | $0.101^{***}$ |
| | (0.003) | (0.004) | (0.007) |
| Board | $0.012^{***}$ | $0.021^{***}$ | $0.047^{***}$ |
| | (0.000) | (0.000) | (0.000) |
| Year fixed effect | Yes | Yes | Yes |
| Industry fixed effect | Yes | Yes | Yes |
| Country fixed effect | Yes | Yes | Yes |
| $R^2$ | 0.585 | 0.536 | 0.392 |
| Adj. $R^2$ | 0.582 | 0.534 | 0.389 |
| Num. obs. | 33110 | 33110 | 33110 |

Table 6 presents the results pertaining to the propensity score matching (PSM) analyses using the three environmental performance variables by replicating the results in Table 4 on a propensity score matched sample of treatment and control firms. ***, ** and * indicate $p$-values of $< 0.01$, $< 0.05$ and $< 0.1$, respectively.

trading on compliance carbon markets, model (2) represents firms that are subject only to a carbon tax, and model (3) represents firms that have adopted only internal carbon pricing. The second set of three models (4-6) presents the results regarding firms that have adopted two CPMs: model (4) represents firms trading on the compliance carbon market that are also subject to a carbon tax, model (5) represents firms trading on the compliance carbon market that have also adopted internal carbon pricing, and model (6) represents firms that are subject to a carbon tax that have also adopted internal carbon pricing. Model (7) assesses the set of firms that have adopted all three types of CPMs simultaneously. Finally, model (8) runs the horse race regression for all possible combinations of CPM adoptions.

These empirical results shed light on the adoption of CPMs. Pedersen et al. (2021) reported that companies facing rising carbon prices should ideally increase production quantity while simultaneously decreasing the volume of emissions. As such, a negative relationship between carbon pricing and carbon emissions is expected. In Table 7, we find that carbon trading and internal carbon pricing have a significant but positive relationship on Carbon Intensity, while a carbon tax on firms has a significant and negative impact on Carbon Intensity. Firms that adopt pairs of CPMs, as shown in models (4) to (6), were associated with significant impacts only from carbon trading and internal carbon pricing. Finally, the presence of all three types of CPMs simultaneously within a firm does not have a significant impact on Carbon Intensity.

The horse race regressions on Energy Intensity shown in Table 8 depict similar results to those observed in the case of Carbon Intensity. Models (1)-(3), which are based on a single CPM, are associated with a significant positive relationship between carbon trading and internal carbon pricing, while the carbon tax seems to induce an emissions reduction. The pairwise CPMs associated with models (4)-(6) show that a combination of carbon trading with a carbon tax instead increases emissions, while a combination of a carbon tax with internal carbon pricing results in a reduction in emissions. Finally, the simultaneous adoption of all three CPMs by a firm does not have any significant impact on Energy

Table 7: Horse Race Regressions of Carbon Pricing Mechanisms on Carbon Intensity

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| CM | 0.076*** | | | | | | | 0.072*** |
| | (0.017) | | | | | | | (0.019) |
| CT | | −0.041*** | | | | | | −0.044*** |
| | | (0.015) | | | | | | (0.015) |
| ICP | | | 0.042** | | | | | 0.045** |
| | | | (0.019) | | | | | (0.019) |
| CM∩CT | | | | 0.067 | | | | 0.016 |
| | | | | (0.041) | | | | (0.044) |
| CM∩ICP | | | | | 0.079** | | | 0.015 |
| | | | | | (0.036) | | | (0.039) |
| CT∩ICP | | | | | | −0.021 | | −0.006 |
| | | | | | | (0.037) | | (0.037) |
| CM∩CT∩ICP | | | | | | | 0.005 | 0.005 |
| | | | | | | | (0.030) | (0.030) |
| Age | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Board Independence | 0.004*** | 0.004*** | 0.004*** | 0.004*** | 0.004 | 0.004*** | 0.004*** | 0.004*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Size | 0.027*** | 0.027*** | 0.027*** | 0.027*** | 0.027*** | 0.027*** | 0.027*** | 0.027*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| Env Innovation | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Leverage | 0.099** | 0.102** | 0.098** | 0.100** | 0.104** | 0.103** | 0.104** | 0.094** |
| | (0.046) | (0.046) | (0.046) | (0.046) | (0.046) | (0.046) | (0.046) | (0.046) |
| Year fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Country fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.403 | 0.403 | 0.403 | 0.403 | 0.403 | 0.403 | 0.403 | 0.403 |
| Adj. $R^2$ | 0.401 | 0.401 | 0.401 | 0.401 | 0.401 | 0.401 | 0.401 | 0.401 |
| Num. obs. | 25333 | 25333 | 25333 | 25333 | 25333 | 25333 | 25333 | 25333 |

Table 7 presents the results of the cross-sectional regressions using Carbon Intensity as a proxy for environmental performance. The first three models (1-3) show the regressions based on the adoption of a single CPM: model (1) represents firms only trading on compliance carbon markets, model (2) represents firms that are subject only to a carbon tax, and model (3) represents firms that have adopted only internal carbon pricing. The second set of three models (4-6) presents the results regarding firms that have adopted two CPMss: model (4) represents firms trading on compliance carbon markets that are also subject to a carbon tax, model (5) represents firms trading on compliance carbon markets that have also adopted internal carbon pricing, and model(6) represents firms that are subject to a carbon tax that have also adopted internal carbon pricing. Model (7) assesses the set of firms that have adopted all three types of CPMs simultaneously. Finally, model (8) runs the horse race regression for all possible combinations of CPM adoptions. In these regressions, since we do not aggregate the presence of different CPMs, the sample size reflects a smaller sample of firms when compared to Table 4. ***, ** and * indicate $p$-values of $< 0.01$, $< 0.05$ and $< 0.1$, respectively. The table reports the coefficient estimates and the standard errors in brackets.

Table 8: Horse Race Regressions of Carbon Pricing Mechanisms on Energy Intensity

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| CM | 0.071*** | | | | | | | 0.085*** |
| | (0.014) | | | | | | | (0.017) |
| CT | | −0.036*** | | | | | | −0.036*** |
| | | (0.013) | | | | | | (0.013) |
| ICP | | | 0.044*** | | | | | 0.045*** |
| | | | (0.017) | | | | | (0.017) |
| CM∩CT | | | | 0.076** | | | | 0.003 |
| | | | | (0.036) | | | | (0.038) |
| CM∩ICP | | | | | −0.042 | | | −0.112*** |
| | | | | | (0.031) | | | (0.034) |
| CT∩ICP | | | | | | −0.164*** | | −0.150*** |
| | | | | | | (0.032) | | (0.032) |
| CM∩CT∩ICP | | | | | | | 0.022 | 0.031 |
| | | | | | | | (0.034) | (0.034) |
| Age | 0.002*** | 0.002*** | 0.002*** | 0.002*** | 0.002*** | 0.002*** | 0.002*** | 0.002*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Board Independence | 0.004*** | 0.004*** | 0.004*** | 0.004*** | 0.004*** | 0.004*** | 0.004*** | 0.004*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Size | 0.049*** | 0.049*** | 0.049*** | 0.049*** | 0.049*** | 0.049*** | 0.049*** | 0.049*** |
| | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| Env Innovation | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** | 0.001*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Leverage | 1.266*** | 1.269*** | 1.264*** | 1.266*** | 1.269*** | 1.271*** | 1.269*** | 1.259*** |
| | (0.040) | (0.040) | (0.040) | (0.040) | (0.040) | (0.040) | (0.040) | (0.040) |
| Year fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Country fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.359 | 0.358 | 0.358 | 0.358 | 0.358 | 0.359 | 0.358 | 0.360 |
| Adj. $R^2$ | 0.357 | 0.356 | 0.356 | 0.356 | 0.356 | 0.357 | 0.356 | 0.358 |
| Num. obs. | 25333 | 25333 | 25333 | 25333 | 25333 | 25333 | 25333 | 25333 |

Tables 8 presents the results of the cross-sectional regressions using Energy Intensity as a proxy for environmental performance. This table only includes firms in the treatment group. The first three models (1-3) show the regressions based on the adoption of a single CPM: model (1) represents firms only trading on compliance carbon markets, model (2) represents firms that are subject only to a carbon tax, and model (3) represents firms that have only adopted internal carbon pricing. The second set of three models (4-6) presents the results regarding firms that have adopted two CPMs: model (4) represents firms trading on compliance carbon markets that are also subject to a carbon tax, model (5) represents firms trading on compliance carbon markets that have also adopted internal carbon pricing, and model(6) represents firms that are subject to a carbon tax and have also adopted internal carbon pricing. Model (7) assesses the set of firms that have adopted all three types of CPMs simultaneously. Finally, model (8) runs the horse race regression for all possible combinations of CPM adoptions. ***, ** and * indicate $p$-values of $< 0.01$, $< 0.05$ and $< 0.1$, respectively. The table reports the coefficient estimates and the standard errors in brackets.

Intensity.

In Table 9, the baseline regression results show that only the carbon tax mechanism has a positive and significant impact on the Environmental Score. According to the horse race results, carbon trading and internal carbon pricing influence the score. Carbon trading and internal carbon pricing must be paired to influence the score. Unlike the cases of Carbon and Energy Intensity, the adoption of all three types of CPMs improves the Environmental Score. The Environmental Score is composed of three elements: emissions, resource use and innovation. Carbon and Energy Intensity are included in the emissions and resources category. The presence of all types of CPMs might be able to foster innovation and influence other environmental strategies, thereby resulting in a better score.

#### 4.1.3 Energy-Intensive versus Other Industries

Carbon pricing mechanisms are popular in energy-intensive industries; however, they can directly affect energy prices and the cost of energy use, leading to an increase in the total costs faced by firms in these industries. To assess the role of CPMs in further detail, a sample of highly carbon-intensive industries has been examined, as shown in Table 7. The sample was based on Climate Watch data provided by the World Resources Institute and focuses on energy, transport, agriculture, forestry and other land use (AFOLU) and manufacturing as carbon-intensive sectors.[2] Table 10 shows that the presence of CPMs in carbon-intensive industries significantly impacts environmental performance to a greater extent than the remaining sectors. However, the implementation of a carbon tax mechanism can accelerate reductions in energy use and ultimately carbon emissions while simultaneously improving environmental performance. The results are similar to those reported by Fu et al. (2023), who found that the introduction of a carbon tax is more likely to benefit carbon-inefficient firms.

Carbon trading and internal carbon pricing should be paired to induce reductions in

[2]https://ourworldindata.org/emissions-by-sector

Table 9: Horse Race Regressions of Carbon Pricing Mechanism on Environmental Score

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| CM | 0.004 | | | | | | | 0.007 |
| | (0.005) | | | | | | | (0.040) |
| CT | | $0.103^{***}$ | | | | | | $0.100^{***}$ |
| | | (0.031) | | | | | | (0.031) |
| ICP | | | 0.024 | | | | | 0.024 |
| | | | (0.036) | | | | | (0.036) |
| CM∩CT | | | | −0.037 | | | | −0.028 |
| | | | | (0.086) | | | | (0.092) |
| CM∩ICP | | | | | $0.124^{*}$ | | | 0.099 |
| | | | | | (0.075) | | | (0.081) |
| CT∩ICP | | | | | | −0.038 | | −0.030 |
| | | | | | | (0.076) | | (0.077) |
| CM∩CT∩ICP | | | | | | | $0.180^{**}$ | $0.176^{**}$ |
| | | | | | | | (0.081) | (0.081) |
| Age | $0.002^{***}$ | $0.002^{***}$ | $0.002^{***}$ | $0.002^{***}$ | $0.002^{***}$ | $0.002^{***}$ | $0.002^{***}$ | $0.002^{***}$ |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Board Independence | $0.019^{**}$ | $0.019^{**}$ | $0.019^{**}$ | $0.019^{**}$ | $0.019^{**}$ | $0.019^{**}$ | $0.019^{**}$ | $0.019^{**}$ |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Size | $0.086^{***}$ | $0.086^{***}$ | $0.086^{***}$ | $0.086^{***}$ | $0.086^{***}$ | $0.086^{***}$ | $0.086^{***}$ | $0.086^{***}$ |
| | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) |
| Env Innovation | 0.000 | $0.001^{**}$ | $0.001^{*}$ | $0.001^{*}$ | $0.001^{*}$ | $0.001^{*}$ | $0.001^{*}$ | $0.001^{**}$ |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Leverage | 0.003 | 0.003 | 0.003 | 0.004 | 0.005 | 0.003 | 0.004 | 0.004 |
| | (0.096) | (0.096) | (0.096) | (0.096) | (0.096) | (0.096) | (0.096) | (0.096) |
| Year fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Country fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 | 0.245 |
| Adj. $R^2$ | 0.243 | 0.243 | 0.243 | 0.243 | 0.243 | 0.243 | 0.243 | 0.243 |
| Num. obs. | 25333 | 25333 | 25333 | 25333 | 25333 | 25333 | 25333 | 25333 |

Tables 9 presents the results of the cross-sectional regressions using the LSEG Environmental Score as a proxy for environmental performance. The first three models (1-3) show the regressions based on the adoption of a single CPM: model (1) represents firms only trading on compliance carbon markets, model (2) represents firms that are subject only to a carbon tax, and model (3) represents firms that have adopted only internal carbon pricing. The second set of three models (4-6) presents the results regarding firms that have adopted two CPMs: model (4) represents firms trading on compliance carbon markets that are also subject to a carbon tax, model (5) represents firms trading on compliance carbon markets that have also adopted internal carbon pricing, and model(6) represents firms that are subject to a carbon tax that have also adopted internal carbon pricing. Model (7) assesses the set of firms that have adopted all three types of CPMs simultaneously. Finally, model (8) runs the horse race regression of all possible combinations of CPM adoptions. ***, ** and * indicate $p$-values of $< 0.01$, $< 0.05$ and $< 0.1$, respectively. The table reports the coefficient estimates and the standard errors in brackets.

Table 10: Disentangling carbon-intensive industries from other sectors

| | Carbon-Intensive Sectors | | | Other Sectors | | |
|---|---|---|---|---|---|---|
| | Carbon Int | Energy Int | Env Score | Carbon Int | Energy Int | Env Score |
| CM | 0.103*** | 0.116*** | 0.040 | −0.001 | 0.003 | −0.073 |
| | (0.020) | (0.022) | (0.044) | (0.021) | (0.024) | (0.059) |
| CT | −0.086*** | −0.053*** | 0.127*** | 0.003 | −0.015 | 0.068 |
| | (0.016) | (0.018) | (0.034) | (0.016) | (0.018) | (0.044) |
| ICP | −0.023 | −0.029 | −0.031 | 0.099*** | 0.146*** | 0.090 |
| | (0.022) | (0.024) | (0.047) | (0.020) | (0.023) | (0.057) |
| CM∩CT | 0.149*** | −0.014 | −0.119 | 0.239*** | 0.105** | −0.147 |
| | (0.050) | (0.056) | (0.108) | (0.044) | (0.050) | (0.124) |
| CM∩ICP | 0.024 | −0.175*** | 0.221*** | −0.162*** | −0.025 | 0.136 |
| | (0.039) | (0.043) | (0.084) | (0.047) | (0.053) | (0.132) |
| CT∩ICP | −0.057 | −0.027 | −0.272*** | −0.184*** | −0.318*** | −1.237*** |
| | (0.040) | (0.044) | (0.086) | (0.039) | (0.044) | (0.108) |
| CM∩CT∩ICP | −0.015 | 0.006 | −0.065 | 0.086** | 0.097** | −0.492*** |
| | (0.043) | (0.047) | (0.092) | (0.040) | (0.045) | (0.111) |
| Year fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Country fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.262 | 0.242 | 0.220 | 0.296 | 0.344 | 0.307 |
| Adj. $R^2$ | 0.259 | 0.238 | 0.216 | 0.291 | 0.340 | 0.303 |
| Num. obs. | 15059 | 15059 | 15059 | 10274 | 10274 | 10274 |

Table 10 shows the results of the regressions for carbon-intensive sectors and others sectors separately. ***, ** and * indicate $p$-values of $< 0.01$, $< 0.05$ and $< 0.1$, respectively. The table reports the coefficient estimates and the standard errors in brackets.

Energy Intensity. The presence of three types of CPMs does not influence any environmental performance measures in carbon-intensive industries. It is important to analyze how noncarbon-intensive industries react to CPMs. Internal carbon pricing is predominant in these sectors. This situation might be related to the fact that carbon-intensive industries are most likely to be covered by emission trading systems and subject to carbon taxes, while other sectors, which are not covered by these approaches, instead resort to the adoption of internal carbon pricing, which is voluntary in nature. However, internal carbon pricing does not seem to have a positive effect on environmental performance. It leads to environmental benefits only when paired with a carbon tax. Trinks et al. (2022) found that, naturally, the internal carbon price might also reflect different capital asset characteristics, such as investment horizon, which are primarily sector-related, thereby reducing uncertainty and allowing this factor to have a stronger impact.

### 4.1.4 Heterogeneities at Regional Levels

This study further investigates the adoption of CPMs at regional levels. Three regions that have adopted carbon trading systems and carbon taxes were included in the subsamples, namely, Europe, Asia, and North America. The results are summarized in Table 11. While the carbon market did not impact environmental performance on its own, we observe that its presence is significantly important in Asia. The impact of a carbon tax as an independent CPM on different environmental performances across all regions is evident. In Europe, such a carbon tax has a positive and significant impact on Energy Intensity. In Asia, it helps improve a firm's Environmental Score, while in North America, it reduces Carbon Intensity. Internal carbon pricing has a significant impact only in Europe. It seems that the adoption of ICP does not motivate firms to reduce their Carbon Intensity in Europe, although it does improve their Environmental Score overall.

Preferences for and the impacts of adopting pairs of CPMs also differ. In Europe, the adoption of a carbon tax alongside internal carbon pricing leads to reductions in Energy Intensity. Asian firms are likely to exhibit reductions in carbon and Energy Intensity based on two pairs, i.e., carbon trading plus internal carbon pricing and a carbon tax plus internal carbon pricing. North American firms tend to receive benefits due to the combination of carbon trading and internal carbon pricing. The adoption of all three types of CPMs simultaneously does not lead to improved environmental performance even at the regional level.

## 4.2 The Roles of Environmental Innovation and Board Independence

### 4.2.1 Environmental Innovation as a Moderator

Firms adopt CPMs to comply with government regulations, reduce costs, or meet stakeholder expectations. Environmental innovation is believed to improve the environmental

Table 11: Carbon Pricing Mechanisms at Regional Level

| | European Union (EU) | | | Asia | | | North America | | |
|---|---|---|---|---|---|---|---|---|---|
| | Carbon Int | Energy Int | Env Score | Carbon Int | Energy Int | Env Score | Carbon Int | Energy Int | Env Score |
| CM | −0.019 | −0.046 | 0.135 | −0.062 | −0.076* | 0.137 | −0.008 | 0.047 | 0.200 |
| | (0.026) | (0.037) | (0.090) | (0.039) | (0.041) | (0.134) | (0.047) | (0.069) | (0.168) |
| CT | 0.025 | 0.098*** | −0.042 | −0.029 | −0.025 | 0.284** | −0.278*** | −0.020 | 0.023 |
| | (0.020) | (0.029) | (0.069) | (0.022) | (0.026) | (0.061) | (0.030) | (0.059) | (0.144) |
| ICP | 0.068** | 0.050 | 0.364*** | −0.018 | 0.041 | −0.021 | 0.039 | 0.094 | 0.262 |
| | (0.027) | (0.038) | (0.091) | (0.029) | (0.033) | (0.079) | (0.038) | (0.080) | (0.194) |
| CM∩CT | −0.016 | 0.071 | −0.177 | −0.040 | −0.045 | −0.289 | −0.310* | −0.354 | 0.341 |
| | (0.055) | (0.077) | (0.187) | (0.093) | (0.094) | (0.320) | (0.175) | (0.245) | (0.617) |
| CM∩ICP | −0.051 | 0.104 | −0.088 | 0.098 | −0.527*** | 0.040 | −0.054 | −0.526* | −1.001 |
| | (0.051) | (0.072) | (0.174) | (0.074) | (0.085) | (0.202) | (0.215) | (0.317) | (0.763) |
| CT∩ICP | −0.089 | −0.280*** | −0.059 | −0.108** | −0.049 | −0.271 | −0.092 | 0.034 | −0.271 |
| | (0.061) | (0.052) | (0.167) | (0.038) | (0.043) | (0.220) | (0.175) | (0.257) | (0.620) |
| CM∩CT∩ICP | 0.027 | −0.142 | 0.280 | −0.028 | 0.048 | −0.173 | 0.031 | 0.010 | −0.057 |
| | (0.052) | (0.073) | (0.178) | (0.069) | (0.097) | (0.237) | (0.289) | (0.196) | (0.470) |
| Year fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Country fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.218 | 0.162 | 0.202 | 0.209 | 0.147 | 0.062 | 0.257 | 0.170 | 0.093 |
| Adj. $R^2$ | 0.216 | 0.160 | 0.199 | 0.206 | 0.142 | 0.057 | 0.252 | 0.164 | 0.086 |
| Num. obs. | 13013 | 13013 | 13013 | 6248 | 6248 | 6248 | 2761 | 2761 | 2761 |

Table 11 shows the results of the regressions at the regional level. ***, ** and * indicate $p$-values of $< 0.01$, $< 0.05$ and $< 0.1$, respectively. The table reports the coefficient estimates and the standard errors in brackets.

aspects of firms by increasing their environmental efficiency through cost savings or by generating opportunities for new, greener incomes (Wedari et al., 2023). The presence of environmental innovation may influence the adoption of CPMs and ultimately environmental performance (Zhou et al., 2023). Previous studies have examined environmental innovation from three different perspectives. First, firms interact with external stakeholders who provide resources that are ultimately invested in innovation (Crilly et al., 2012). Second, through the shared values established by CPMs, a positive organizational atmosphere is created that enhances firms' ability to innovate (Wang et al., 2023; Zhang, 2022). This entails that environmental innovation can be an important moderating factor that can potentially enhance the effectiveness of CPMs. Third, carbon pricing might generate customer loyalty, which in turn encourages firms to innovate in response (Kim, 2017). Based on these arguments, we introduce the interaction term between CPMs and environmental innovation into our horse race regressions and examine the role of innovation in increasing the effectiveness of CPMs with regard to environmental performance.

The results are presented in Table 12. We observe that the coefficient for the interaction term between CPM(s) and environmental innovation is significant only with regard to $Carbon\ Tax$ x $Innovation$ for Carbon Intensity, $ICP$ x $Innovation$ for Environmental Score, $CM \cap ICP$ x $Innovation$ for Carbon Intensity and Energy Intensity, $CT \cap ICP$ x $Innovation$ for Energy Intensity and $CM \cap CT \cap ICP$ x $Innovation$ for Carbon Intensity. These findings imply that the improved environmental performance caused by the CPMs differs across firms that exhibit different environmental innovation commitments.

#### 4.2.2 Board Independence as a Moderator

Liao et al. (2015) argued that a firm's climate strategy often involves large investments, which have complex consequences that may affect stakeholder groups in distinct ways. For example, some stakeholders may focus on financial returns, whereas others are concerned with environmental impacts. Therefore, a board's environmental decision may represent a compromise among conflicting demands. Therefore, a board must be suffi-

Table 12: Innovation as a Moderating Factor

| | Carbon Intensity | Energy Intensity | Env. Score |
|---|---|---|---|
| CM | 0.043* | 0.087*** | 0.004 |
| | (0.025) | (0.025) | (0.053) |
| CM*Innovation | 0.000 | −0.000 | 0.001 |
| | (0.001) | (0.001) | (0.001) |
| CT | −0.075*** | −0.021 | 0.091** |
| | (0.020) | (0.020) | (0.042) |
| CT*Innovation | 0.001** | 0.000 | 0.000 |
| | (0.000) | (0.000) | (0.001) |
| ICP | 0.041 | 0.045* | 0.083 |
| | (0.026) | (0.026) | (0.054) |
| ICP*Innovation | 0.001 | 0.001 | 0.003** |
| | (0.001) | (0.001) | (0.001) |
| CM∩CT | 0.079 | −0.159*** | 0.059 |
| | (0.058) | (0.058) | (0.121) |
| CM∩CT*Innovation | −0.002 | 0.002 | −0.005 |
| | (0.001) | (0.001) | (0.003) |
| CM∩ICP | 0.096* | −0.174*** | 0.205* |
| | (0.054) | (0.054) | (0.113) |
| CM∩ICP*Innovation | −0.003*** | 0.003*** | −0.002 |
| | (0.001) | (0.001) | (0.002) |
| CT∩ICP | 0.006 | −0.451*** | 0.022 |
| | (0.065) | (0.065) | (0.135) |
| CT∩ICP*Innovation | 0.000 | 0.005*** | −0.002 |
| | (0.001) | (0.001) | (0.002) |
| CM∩CT∩ICP | 0.150*** | 0.048 | 0.251** |
| | (0.052) | (0.052) | (0.108) |
| CM∩CT∩ICP*Innovation | 0.003*** | 0.000 | −0.002 |
| | (0.001) | (0.001) | (0.002) |
| Year fixed effect | Yes | Yes | Yes |
| Industry fixed effect | Yes | Yes | Yes |
| Country fixed effect | Yes | Yes | Yes |
| $R^2$ | 0.004 | 0.135 | 0.005 |
| Adj. $R^2$ | 0.004 | 0.134 | 0.004 |
| Num. obs. | 25333 | 25333 | 25333 |

Table 12 shows the results of the regressions with innovation as a moderating effect. ***, ** and * indicate $p$-values of $< 0.01$, $< 0.05$ and $< 0.1$, respectively. The table reports the coefficient estimates and the standard errors in brackets.

ciently independent to address the issues raised by various stakeholders. The appointment of independent directors, who are less aligned with the current management and are thus more likely to be inclined to encourage firms to adopt the CPMs demanded by stakeholders, is an effective monitoring mechanism that restricts the opportunistic behaviors of top executives posited by agency theory (Hillman and Dalziel, 2003). Therefore, we introduce the interaction term between CPMs and board independence into our horse race regression.

The results presented in Table 13 show that the coefficient of interaction between $CPM$ x $Board\ Independence$ is significant with regard to $CT$ x $Board\ Independence$ for Carbon Intensity and Environmental Score, $ICP$ x $Board\ Independence$ for Energy Intensity and Environmental Score, $CM \cap CT$ x $Board\ Independence$ for carbon and Energy Intensity, $CT \cap ICP$ x $Board\ Independence$ for Energy Intensity and Environmental Score, and $CM \cap CT \cap ICP$ x $Board\ Independence$ only for the Environmental Score. These results clearly indicate that while the adoption of $CM \cap CT \cap ICP$ had previously generated nonsignificant results and did not seem to influence environmental performance, the results are different when board independence is used as a moderator. The interaction between $CM \cap CT \cap ICP$ and board independence exhibits a statistically significant coefficient with regard to the Environmental Score.

Implementing three types of CPMs would necessitate further improvements in innovation and board independence, thus enabling their benefits to extent to the improvement of environmental performance. It can be argued that the adoption of multiple CPMs simultaneously also requires more resources to be mobilized and invested; it also entails more pressure to reduce emissions from diverse stakeholders. If firms are unable to employ their resources efficiently and obtain support from the board, CPMs are thus not effective as an environmental measure.

Table 13: Board Independence as a Moderating Factor

| | Carbon Intensity | Energy Intensity | Env. Score |
|---|---|---|---|
| CM | 0.035 | 0.038 | 0.209*** |
| | (0.031) | (0.031) | (0.064) |
| CM*Board Independence | 0.000 | 0.001 | 0.004*** |
| | (0.001) | (0.001) | (0.001) |
| CT | −0.120*** | −0.022 | 0.203*** |
| | (0.022) | (0.022) | (0.047) |
| CT*Board Independence | −0.002*** | 0.000 | 0.002*** |
| | (0.000) | (0.000) | (0.001) |
| ICP | 0.056* | 0.184*** | 0.268*** |
| | (0.030) | (0.030) | (0.063) |
| ICP*Board Independence | 0.000 | −0.003*** | 0.003** |
| | (0.001) | (0.001) | (0.001) |
| CM∩CT | −0.089 | −0.016 | −0.138 |
| | (0.065) | (0.065) | (0.135) |
| CM∩CT*Board Independence | 0.004*** | −0.002* | 0.001 |
| | (0.001) | (0.001) | (0.003) |
| CM∩ICP | −0.070 | −0.101* | 0.262** |
| | (0.061) | (0.061) | (0.126) |
| CM∩ICP*Board Independence | 0.001 | 0.001 | −0.003 |
| | (0.001) | (0.001) | (0.002) |
| CT∩ICP | 0.100* | −0.225*** | 0.254** |
| | (0.060) | (0.060) | (0.126) |
| CT∩ICP*Board Independence | −0.002* | 0.001 | 0.009*** |
| | (0.001) | (0.001) | (0.003) |
| CM∩CT∩ICP | 0.184*** | 0.019 | 0.403*** |
| | (0.055) | (0.055) | (0.114) |
| CM∩CT∩ICP*Board Independence | −0.002 | 0.001 | 0.007*** |
| | (0.001) | (0.001) | (0.003) |
| Year fixed effect | Yes | Yes | Yes |
| Industry fixed effect | Yes | Yes | Yes |
| Country fixed effect | Yes | Yes | Yes |
| $R^2$ | 0.005 | 0.135 | 0.006 |
| Adj. $R^2$ | 0.004 | 0.134 | 0.006 |
| Num. obs. | 25333 | 25333 | 25333 |

Table 13 shows the results of the regressions with board independence as a moderating effect. ***, ** and * indicate $p$-values of $< 0.01$, $< 0.05$ and $< 0.1$, respectively. The table reports the coefficient estimates and the standard errors in brackets.

## 4.3 Discussion

This study assesses the adoption of multiple types of CPMs and their influence on environmental performance as measured in terms of Carbon Intensity, Energy Intensity, and Environmental Score. The first conclusion pertaining to the adoption of CPMs is that a carbon tax has a much stronger influence than carbon trading or internal carbon pricing. It can be deduced that a carbon tax has more significant impacts on reducing emissions and energy consumption. Unlike situations featuring a cap-and-trade system, in which firms are allocated emission allowances for free, under a carbon tax, firms must compensate for their emissions, which affects their profitability and motivates them to decarbonize (Fu et al., 2023). Furthermore, carbon taxes provide more certainty than carbon trading. Future abatement costs are, however, uncertain (for example, due to uncertainty regarding fuel prices and the availability and costs of clean technologies), and governments cannot choose certainty over both prices and emissions. In cases of carbon taxation, governments can provide certainty regarding future emissions prices by specifying the future trajectory of tax rates. Parry et al. (2022) highlighted the fact that such price-related uncertainty in carbon trading can deter the adoption of clean energy and technology and ultimately fail to generate any improvements in environmental performance.

Carbon trading ignores small-scale emitters in sectors that are covered by the ETS, but their share of emissions can also be modest. Carbon trading often suffers from drawbacks in countries featuring limited institutional capacity or highly concentrated trading due to a limited number of firms (Muñoz, 2021). In contrast, internal carbon pricing significantly influences Carbon Intensity and Energy Intensity. However, it does not promote overall environmental performance. The CDP reported that the disclosed level of internal carbon price exceeds 'external' carbon prices in cases featuring both carbon pricing systems and relevant legislation, suggesting that the latter might reflect more concerns regarding future carbon regulation. It is also worth noting that the presence of internal carbon prices exhibit substantial differences across firms, implying uncertainty in price dynamics.

This study proposes the adoption of multiple CPMs by firms. While carbon trading and internal carbon pricing, taken individually, cannot improve environmental performance, it is notable that when they are paired, more significant results are obtained. This finding is in line with the extant literature. For instance, Trinks et al. (2022) argued that the use of internal carbon prices is driven by external carbon constraints and by firms' exposure to formal carbon pricing. The presence of societal risk and stringent climate policies due to ETSs can provide predictable pathways that can help firms mitigate the misalignment of their investments by reference to the internal carbon price. The implementation of both carbon taxes and ETSs is common in some countries. Taxes have been applied to the same sources of emissions as are targeted by ETSs to establish a more robust price signal. However, throughout this study, the bilateral adoption of CPMs of tax and trading did not effectively impact firms.

A small sample of firms have adopted all three types of CPMs, i.e., $CM \cap CT \cap ICP$. The results do not support the effectiveness of robust presence of all three CPMs as their coefficients are insignificant. Further analysis shows that the potential of multiple CPMs can be unlocked by environmental innovation and board independence. Firms in this sample are subject to increasing costs and pressure from diverse stakeholders.

## 4.4 Policy Implications

Ensuring deep decarbonization at the pace necessary to mitigate the worst impacts of climate change has emerged as an urgent challenge for policy makers. Carbon pricing has been identified as an effective tool to reach that goal, as it can help make low- and zero-carbon energy more competitive than high-carbon alternatives. This study provides insights to policy makers regarding the effectiveness of CPMs at the micro level.

Economists overwhelmingly support the implementation of an effective carbon price to encourage decarbonization. However, historically, the focus of such research has been on a metric known as the social cost of carbon, i.e., an estimate of the marginal damages of an additional ton of $CO_2$ emissions. Kaufman et al. (2020) reported on the uncertainty associated with the use of this metric. International climate change negotiations are rapidly shifting to net-zero emissions targets, which must be reflected in the carbon price calculations made by policy makers and firms. Currently, no international standards have been established for businesses with regard to determining their internal carbon pricing, and the adoption of an inappropriate rate might fail to promote carbon emission reductions.

Models that simulate economic and energy systems are developed using historical data regarding production, consumption and market dynamics, which may be a reasonable assumption in the near term. Focusing on the near term entails that $CO_2$ price estimates should not be unduly influenced by assumptions regarding the highly uncertain long-term evolution of technologies and behaviors. With regard to carbon trading, price volatility can be controlled using mechanisms such as price floors, banking/borrowing provisions and a transparent future emissions cap.

Nations such as Finland, Norway, Sweden, and Denmark were already front-runners in the implementation of carbon regulations in the early 1990s. They show that the choice of relevant time horizon should be based on a steady state of spatial interactions among tax policies over time. In some scenarios, firms might need more time to adjust their strategies in response to a policy shock at the national or international level.

# 5 Conclusions

Due to the growing emphasis on the adoption of carbon pricing mechanisms (CPMs) worldwide, demand for research on CPMs is increasing, particularly with regard to whether such mechanisms are able to induce emission reductions and improve environmental performance. Accordingly, researchers have attempted to explore this relationship by studying the adoption of carbon pricing on an individual basis; that is, carbon trading, carbon tax, and internal carbon pricing have been analyzed individually in the literature. To our knowledge, this study is the first to consider the adoption of both single and multiple CPMs simultaneously.

The primary research question pursued in this study is whether environmental performance (as measured in terms of Carbon Intensity, Energy Intensity, and Environmental Score) improves due to the adoption of CPMs. The results indicate that the presence of a CPM significantly improves Carbon Intensity and the Environmental Score. Further analysis shows that a carbon tax is the only mechanism that can improve environmental performance on its own, as carbon trading and internal carbon prices must be paired to have significant effects. Surprisingly, the presence of all three types of CPMs simultaneously does not influence environmental performance. Based on separate examinations of carbon-intensive sectors and other sectors, we suggest that the CPMs adopted by high carbon-intensive firms are more likely to reduce emissions and improve environmental performance. The roles of environmental innovation and board members' independence as moderating variables have been uncovered. The presence of multiple CPMs requires a high rate of environmental innovation and strong board independence to improve environmental performance.

This study contributes to the literature by providing new insights into the adoption of single versus multiple CPMs. Our study notably emphasizes the determining role of the carbon tax in this context and suggests that environmental performance should be fostered through the adoption of a carbon tax. The findings of this study have important implications for managers and policy makers who must confront the challenges of decarbonizing firms and assigning a price to carbon. Future research can assess the rate of carbon pricing and compare the corresponding impacts on emission reductions. A current trend involves reporting the carbon pricing rates adopted internally by firms. In addition, the impact of the adoption of carbon pricing can be determined using different measures of environmental performance beyond the level of emissions and overall Environmental Scores. The benefits and disadvantages of CPMs can also be explored since these mechanisms can enable some firms to obtain competitive advantages but represent only costs for other firms.

# Appendices

## Appendix A: Countries with Emission Trading Systems (ETS)

| Countries | Year of Implementation | Scope |
|---|---|---|
| EU ETS | 2005 | The system covers activities from the power sector, manufacturing industry, and aviation (including flights from the EEA to the United Kingdom). |
| California ETS | 2012 | The California CaT applies to GHG emissions (CO2, CH4, N2O, SF6, HFCs, PFCs, NF3, and other fluorinated GHGs) from the industry, power, transport and buildings sectors and includes industrial process emissions. |
| RGGI | 2009 | RGGI covers CO2 emissions only from the power sector. |
| Quebec | 2013 | The Quebec CaT applies to GHG emissions from the industry, power, transport and buildings sectors and includes industrial process emissions. |
| China National ETS | 2021 | The ETS initially only applies to CO2 emissions from the power sector, including combined heat and power and captive power plants from other sectors. |
| South Korea ETS | 2015 | The ETS initially only applies to CO2 emissions from the power sector, including combined heat and power and captive power plants from other sectors. |

## Appendix B: Countries adopting Carbon Tax

| Countries | Year of Implementation | Scope |
|---|---|---|
| Argentina | 2018 | The tax covers almost all liquid fuels and some solid products mineral coal and petroleum coke. |
| British Columbia | 2008 | The BC carbon tax applies to all fossil fuels and tires combusted for heat and energy, with some exemptions for industry, aviation, agriculture and transport users |
| Baja California | 2020 | The Baja California carbon tax applies to CO2 emissions from all sectors.The tax covers all liquid fossil fuels. |
| Chile | 2017 | The Chile carbon tax applies to CO2 emissions from mainly the power and industry sectors.The tax reform approved in 2020 modifies the threshold, establishing that as of 2023 it will apply to installations that emit 25,000t CO2 or more, as well as to those that release more than 100 tons of particulate matter into the air each year. The tax covers all fossil fuels. |
| Columbia | 2017 | The Colombia carbon tax applies to GHG emissions from all sectors with some minor exemptions.The tax covers all liquid and gaseous fossil fuels used for combustion. |
| Denmark | 1992 | The Denmark carbon tax applies to GHG emissions from mainly the buildings and transport sectors as there are (partial) exemptions for other sectors. |
| Estonia | 2000 | The Estonia carbon tax applies to CO2 emissions from industry and power sectors.The tax covers all fossil fuels used to generate thermal energy. |
| Finland | 1990 | The Finland carbon tax applies to CO2 emissions from mainly the industry, transport and buildings sectors with some exemptions for industry. The tax covers all fossil fuels except for peat. |
| France | 2014 | The French carbon tax applies CO2 emissions from mainly the industry, buildings and transport sectors with some exemptions for these and other sectors. |
| Iceland | 2010 | The Iceland carbon tax applies to CO2 emissions from all sectors with some exemptions for the industry, power, aviation and international shipping sectors |
| Ireland | 2010 | The Ireland carbon tax applies to CO2 emissions from all sectors with some exemptions for the power, industry, transport and aviation sectors. |
| Japan | 2012 | The Japan carbon tax applies to CO2 emissions from the combustion of fossil fuels across all sectors with some exemptions for the industry, power, agriculture and transport sectors. |
| Latvia | 2004 | The Latvia carbon tax applies to CO2 emissions from the industry and power sectors not covered under the EU ETS. |
| Luxembourg | 2021 | Luxembourg carbon tax applies to fossil fuels used for transportation and heating. Fossil fuels used for electricity generation are exempt from the carbon tax. |
| Mexico | 2014 | The Mexican carbon tax applies to CO2 emissions from all sectors. |
| Netherlands | 2021 | The Netherlands carbon tax applies to emissions from industry and waste sectors. |
| Norway | 1991 | The Norwegian taxes on emissions of GHGs applies to GHG emissions from all sectors with some exemptions for certain sectors. |

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| Poland | 1990 | The Poland carbon tax applies to GHG emissions from all sectors with some exemptions for certain entities. |
| Portugal | 2015 | The Portugal carbon tax applies to CO2 emissions from mainly the industry, buildings and transport sectors with some exemptions for these and other sectors. |
| Singapore | 2019 | The Singapore carbon tax applies to direct emissions from facilities emitting 25kt CO2 or more in a year, covering carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons. The carbon tax is applied on all sectors without exemption as long as the facility meets the emissions threshold. |
| Slovenia | 1996 | The Slovenia carbon tax applies to GHG emissions from mainly the buildings and transport sector as there are exemptions for other sectors. |
| South Africa | 2019 | The Carbon Tax covers all types of fossil fuels combusted by large businesses across industry, power, and transport sectors. |
| Spain | 2014 | The Spanish carbon tax applies to fluorinated GHG emissions (HFCs, PFCs, and SF6) only from all sectors with some exemptions for certain sectors. |
| Sweden | 1991 | The Swedish carbon tax applies to CO2 emissions from mainly the transport and buildings sector as there are many (partial) exemptions for other sectors. |
| Switzerland | 2008 | The Swiss CO2 levy applies to CO2 emissions generated from fossil heating and process fuels when used in the industry, power and buildings sectors. |
| Ukraine | 2011 | The Ukraine carbon tax applies to CO2 emissions from stationary sources, so mainly the industry, power and buildings sectors and all types of fuels. |

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