Carbon Taxes and Emission Trading Systems: Which One Is More Effective in Reducing Carbon Emissions? —A Meta-analysis

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Abstract

The effectiveness of carbon-pricing policies, particularly carbon taxes and emissions-trading systems (ETSs), in reducing carbon emissions remains a subject of debate, and the empirical evidence is mixed. To address this issue, we conduct a meta-analysis to assess and compare the effectiveness of these two types of policies based on 81 studies conducted from 2011 to 2022. Our analysis shows that both carbon taxes and ETSs have a reduction effect on carbon emissions but that the effect of the former is stronger than the latter. These findings are consistent across the models and samples in the studies. We then document the heterogeneity of the effects of these policies and find that country-level characteristics, such as financial development and GDP growth rates, can enhance the effectiveness of either carbon taxes or ETSs. Furthermore, the reduction effect of carbon taxes is strongest in Asia (excluding Japan) while that of ETSs is strongest in the United States. We also find that carbon taxes and ETSs are particularly effective in reducing carbon emissions in carbon dioxide-intensive industries and emissions from fossil fuels. Overall, our study highlights the effectiveness of carbon-pricing policies to address the environmental challenges associated with climate change and facilitate the achievement of sustainable development goals for carbon neutrality.

Keywords: Carbon taxes; Emissions trading schemes; Carbon emissions; Meta-analysis
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1. Introduction

There is compelling evidence that climate change poses a threat to the sustainability of human society (Tol 2010) and is a significant challenge that influences human life (Doğan, Driha, Balsalobre Lorente, and Shahzad 2020). Policymakers, social scientists, economists, and stakeholders in various fields are actively seeking effective strategies for reducing emissions of carbon dioxide (CO2) and other greenhouse gases (GHGs), which are the leading contributors to climate change and environmental pollution (Su, Umar, Kirikkaleli, and Adebayo 2021). Among various policies, carbon-pricing policies have garnered much attention as potential tools for reducing the emissions of CO2 and other GHGs. Carbon pricing involves assigning a financial value to carbon emissions through the implementation of either a carbon tax or an emissions-trading system (ETS) to encourage businesses and individuals to reduce their carbon footprints. These policies create economic incentives to adopt cleaner and more sustainable practices, promote energy efficiency, and invest in renewable energy sources. The High-Level Commission on Carbon Pricing and Competitiveness (2017) affirms that carbon pricing is a highly effective, adaptable, and cost-efficient strategy for mitigating GHG emissions. There is an increasing trend of adoption and expansion of carbon-pricing mechanisms worldwide. Currently, 30 carbon taxes and 31 ETSs have been implemented globally that together cover approximately 22% of worldwide emissions (World Bank 2020).

However, the effectiveness of carbon-pricing policies in reducing carbon emissions remains a matter of debate and, therefore, requires further investigation. While some studies find that such policies significantly reduce emissions, others find very limited impact (e.g., Lin and Li 2011; Shen, Tang, and Zeng 2020; Tomáková 2021; Pretis 2022). Furthermore, when comparing the effectiveness of specific carbon pricing mechanisms such as ETSs and carbon taxes, studies have produced contradictory results. Some studies suggest that carbon taxes may be more effective than ETSs because they provide clear and direct incentives for emitters to reduce their carbon footprints (e.g., Bonilla, Coria, and Sterner 2012; Goulder and Schein 2013; International Monetary Fund [IMF] 2019), while other studies show the opposite because carbon tax, as a form of price intervention, increases uncertainty and volatility regarding the levels of carbon emissions (e.g., Im and Kim 2022). The lack of consensus on the relative effectiveness of ETSs and carbon taxes contributes to the complexity of this issue. Green (2021) suggests that a comprehensive meta-analysis is required to clarify the role of carbon-pricing policies in reducing carbon emissions across regions and contexts.

Therefore, in this paper, we conduct what is to the best of our knowledge the first meta-analysis comparing the effectiveness of carbon taxes and ETSs in reducing carbon emissions. A meta-analysis provides a formal quantitative framework for researchers to document and explain study-to-study variation in outcomes from a perspective free from the biases associated with the judgments of individuals. This approach is especially useful in the setting for the present study, which is characterized by a wide range of data sources, from country-level to firm-level studies, that the original single-country studies cannot fully capture. Our meta-analysis quantifies the overall effect of carbon-pricing policies by increasing the number of observations and the range of sources and time periods compared with the original studies, thereby reducing the impact of any sampling errors within individual studies and controlling for unobserved between-study heterogeneity. We also identify the sources of disagreement among the studies and introduce new institutional factors—the GDP growth rate, financial development, tax enforcement, countries' development status, and the presence of highly carbon emission-intensive industries—to test our hypotheses regarding the economic drivers of the differences in the effectiveness of the carbon-pricing policies across economies.

Based on 81 studies of the effectiveness of carbon taxes or ETSs in reducing carbon emissions conducted between 2011 to 2022, we find that both pricing policies have a significant reduction effect on emissions and that the former are more effective than the latter. Our results are robust irrespective of the model used (i.e., random- or fixed-effect) when calculating the average effect size per study, whether the sample is restricted to published papers, or whether the sample is restricted to studies at the firm or plant level. Our meta-analytic tests show no significant shortcomings in our findings with respect to homogeneity or publication bias for either carbon taxes or ETSs.

We then conduct various analyses of the heterogeneity in the effectiveness of these policies in reducing carbon emissions. First, we expect country-level factors to contribute to their effectiveness and find, indeed, the impacts to be greater in regions with high rates of GDP growth and financial development. The impact of ETSs on carbon emission reduction is especially pronounced in such regions. Second, we investigate regional variation in the effectiveness of carbon taxes and ETSs. We find carbon taxes to be more effective in Asia (excluding Japan) than in the United States, European countries, or Canada, while ETSs are more effective in the United States than in China or European countries. Lastly, we predict that the intensity of industry-level emissions of CO2 and other forms of carbon help to determine the effectiveness of carbon-pricing policies. We find that carbon taxes and ETSs are more effective in CO2-intensive industries than in other emission dominated industries. Meanwhile, carbon taxes are more effective than ETSs when emissions are derived from fossil fuels than from other sources such as electricity or coal.

Our study contributes to the literature in several ways. First, our paper provides a comprehensive analysis of the role of carbon taxes and ETSs in reducing carbon emissions using a meta-analytic approach. Meta-analysis is a powerful methodology because it involves the integration of findings from multiple studies to facilitate the identification of trends, patterns, and overall effects across a wide range of studies and allows for conclusions that are more generalizable than those of the individual studies analyzed. By overcoming the limitations of individual studies and combining the results of numerous studies, we are able to estimate the effectiveness of carbon-pricing policies in reducing carbon emissions more accurately and to generalize the conclusions of the studies. Our meta-analysis, then, contributes to the literature by offering a more comprehensive and reliable account of the role of carbon taxes and ETSs in achieving sustainable development goals related to carbon reductions.

Second, our study confirms the overall effectiveness of carbon taxes and ETSs in reducing carbon emissions. More specifically, our analysis of the various effect sizes indicates that the implementation of these carbon-pricing policies can reduce carbon emissions. Our study contributes to the literature on these policies by presenting a comparison of the effectiveness of carbon taxes and ETSs that provides insights that can inform the ongoing debate regarding the choice of policy instruments for reducing carbon emissions. The empirical evidence that we present supports the argument that, in general, carbon taxes are more efficient and effective than ETSs in achieving carbon-neutrality goals. This finding can help policymakers, researchers, and other stakeholders select the appropriate policy instruments. Furthermore, our comparison of carbon taxes and ETSs highlights the specific mechanisms and characteristics that contribute to the effectiveness of carbon-pricing policies and offers insights into the design and implementation considerations that can enhance the effectiveness of these policies, especially carbon taxes.

Third, we offer better explanations for how and why carbon-pricing policies reduce carbon emissions by identifying and documenting the heterogeneity in their effectiveness. For example, we elucidate and highlight the impact of regional economic, political, legal, and technological characteristics in the effectiveness of carbon-pricing policies. Our study thus enriches the understanding of the complexities involved in implementing these policies and provides valuable guidance for the design of context-specific and effective pricing strategies.

The remainder of the paper is organized as follows. In the next section, we summarize the previous literature on the relationship between carbon-pricing policies and reductions in carbon emissions. In Section 3, we discuss the methodology for the meta-analysis and the data collection process. In Section 4, we present our overall results. In Section 5, we summarize our findings, offer conclusions, and discuss practical implications of the study. In Section 6, we highlight the limitations of this study and suggest directions for future research.

2. Literature Review

2.1. Institutional background of carbon-pricing policies

Carbon policies are a set of regulations, laws, and initiatives that governments and organizations implement to address and mitigate carbon emissions and climate change. The major aims of these policies are to reduce emissions of GHGs, particularly CO2, which is the primary contributor to global warming, and to foster sustainable practices (Edenhofer 2015). The pricing of GHG emissions is widely recognized in the environmental economics literature as a key policy instrument for addressing climate change (e.g., Bonilla, Coria, and Sterner 2012). The carbon-pricing approach involves placing a monetary value on emissions to create economic incentives to reduce emissions and transition to a low-carbon economy (Boyce 2018). The implementation of effective financial mechanisms encourages companies and countries to lower their emissions by adopting more efficient practices and/or transitioning to cleaner energy sources (Skovgaard and van Asselt 2019). The following discussion distinguishes the two main types of carbon-pricing mechanisms, which are, as has been seen, carbon taxes and ETSs.

2.2. Carbon taxes

A carbon tax is a policy instrument that involves the imposition of surcharges on the consumption of fossil fuels and other major contributors to GHG emissions based on their carbon content (Green 2021). A fixed price on carbon emissions (Freebairn 2014) is typically levied per unit of CO2 emitted by the burning of such fossil fuels as coal, oil, and natural gas

(Hsu 2012). The purpose of a carbon tax is to hold emitters financially responsible for their carbon output and mitigate the negative environmental impact of GHG emissions. Carbon taxes are often collected at the point at which fossil fuels are produced or imported, thereby effectively increasing the cost of carbon-intensive energy sources and, in turn, increasing the prices for goods and services that rely heavily on these fuels. The financial burden of taxes on emissions encourages businesses and individuals to adopt cleaner technologies and practices and, ultimately, reduce their carbon emissions.

Studies of the effectiveness of carbon taxes have shown mixed results. Most have found that such taxes can, indeed, lead to a decrease in emissions across countries and industries (e.g., Kim, Han, and Moon 2011; Morley 2012; Kotnik and Škulj 2014; Alper 2018; Andersson 2019; Kokotović et al. 2019; Ghazouani, Jebli, and Shahzad 2021; Wang, Khurshid, Qayyum, and Calin 2022). Their findings tend to indicate that carbon taxes can stimulate innovation, promote energy efficiency, and encourage the adoption of cleaner technologies. For example, Alper (2018), using data from 1995 to 2015, finds a negative effect of carbon taxes on carbon emissions in 18 European countries, with a 1% increase in environmental taxes reducing CO2 emissions by approximately 0.9%. Similarly, Kim, Han, and Moon (2011) show that a gasoline tax has a significant impact in terms of reducing the CO2 emissions from the transportation sector in South Korea, and Andersson (2019) shows that the implementation of the carbon tax and value-added tax (VAT) has a negative effect on CO2 emissions from transportation in Sweden. Metcalf (2019) likewise shows that a carbon tax can be a cost-effective policy tool for reducing GHG emissions in the United States, and Sarigül and Topcu (2021), using data from 1994 to 2015, find that environmental taxes have a significantly negative effect on CO2 emissions in Turkey, while Bashir, Ma, Shahbaz, and Jiao (2020) find a similar effect for OECD economies from 1995 to 2015.

Among several studies that report no significant effect of carbon taxes on carbon emissions, Pretis (2022) finds that the introduction of a carbon tax in British Columbia, Canada, has no statistically significant effect on the aggregate level of CO2 emissions. Lin and Li (2011) focus on the effect of carbon taxes on per capita CO2 emissions in EU countries, including Finland, Denmark, Sweden, the Netherlands, and Norway, and find a significant reduction of CO2 emissions in Finland but not in Denmark, Sweden, or the Netherlands owing to tax exemptions granted to certain energy-intensive industries and a substantial increase in emissions in Norway because of rapid growth of energy products market.

Factors such as the elasticity in the demand for carbon-intensive products, the availability of alternative energy sources, regulatory frameworks, and complementary policies can also influence the effectiveness of carbon taxes. Thus, Pretis (2022) shows that the impact of carbon taxes varies across sectors. Wolde-Rufael and Mulat-Weldemeskel (2021) find an inverted U-shaped relationship between the impact of environmental taxes and policy stringency on CO2 emissions in seven emerging economies from 1994 to 2015. Specifically, strict environmental policies do not lead to significant reductions in CO2 emissions at first, but, once a certain threshold of stringency is reached, improvements occur in environmental quality. This finding suggests that there is a minimum level of policy stringency for the achievement of desired environmental outcomes.

2.3. ETSs

ETSs, often known as “cap-and-trade” or “carbon markets,” are another type of carbon-pricing mechanism. Under an ETS, a government sets a finite limit or cap on the total GHG emissions generated by a specific sector or jurisdiction. The caps are usually based on scientific and policy considerations relating to the achievement of emission-reduction targets. Permits allocated to participating firms or entities, either freely or through auctioning, confer the right to emit a certain amount of GHGs. Each firm is assigned a number of permits corresponding to its emission allocations (Green 2021).

Firms have flexibility in the use of these permits to meet their emissions targets. Those that emit more GHGs than their allocated allowances must purchase additional permits to cover the excess emissions from other firms in the market. Conversely, those that emit less than their allocated allowance have the option to sell their surplus permits to other firms that need additional permits. In this market for trading emissions permits, firms can buy and sell based on their need to generate emissions, with supply and demand dynamics determining the allowance price (Skovgaard and van Asselt 2019). Trading allowances enable firms to determine the most cost-effective means of meeting their emission targets and incentivize emission reductions by providing financial benefits to firms that are able to reduce their emissions at a relatively low cost and encouraging the adoption of cleaner technologies and practices.

While there is no consensus in the literature regarding the effectiveness of ETSs in reducing carbon emissions, most studies suggest that they can be an effective policy tool. However, their effectiveness may vary across contexts, including regional and national circumstances, sector-specific characteristics, and the presence of complementary policies (e.g., Zhang, Duan, and Deng 2019; Chen Shi and Wang 2020; Hu, Ren, Wang, and Chen 2020; Arimura and Abe 2021; Huang, Shen, Miao, and Zhang 2021; Peng, Qi, and Cui 2021). For instance, Hu, Ren, Wang, and Chen (2020) describe a CO2 ETS pilot policy that reduces emissions within the regulated industries in the pilot areas of China and find that the effect varies across regions, with better performance observed in areas with higher levels of environmental enforcement and marketization. Huang, Shen, Miao, and Zhang (2021) find a negative association between an ETS and pollutant emissions in pilot cities in China using data from 2003 to 2016 and that its impact is more pronounced in cities with larger populations, higher levels of financial development, and poorer air quality. Arimura and Abe (2021) discuss the effectiveness of the Tokyo ETS in reducing carbon emissions in the office building sector. Peng, Qi, and Cui (2021) find that a carbon ETS in China results in a reduction in carbon emissions and emission intensity, mainly because of improvements in energy efficiency. Similarly, Wang et al. (2022) find that China's ETS improves technological innovation and energy efficiency and, ultimately, promotes sustainable development and climate-change mitigation.

However, several studies show that ETSs have no effect on carbon emissions or even increase them. For example, Zhang, Duan, and Deng (2019) find that flaws in the design of a pilot ETS program in China and companies' lack of familiarity with the scheme initially render its impact negligible in decreasing the carbon intensity of the industrial subsectors covered. Similarly, Shen, Tang, and Zeng (2020) show that China's ETS pilot programs do not significantly reduce the impact of the large-scale and state-owned firms that are major contributors to carbon emissions. An examination by Tomáková (2021) of the impact of the EU ETS through its three phases on the Czech Republic's CO2 emissions, carbon fuel intensity, and carbon intensity of production using installation-level financial, environmental, and energy data from 2005 to 2019 shows that it has no significant effect on either carbon emissions or carbon intensity.

2.4. Comparison of carbon taxes and ETSs

A key difference between carbon taxes and ETSs is the method used to determine the price and quantity of the emissions. Carbon taxes offer a clear predetermined price for each unit of carbon emissions set by the government and, thus, certainty in terms of costs. However, such taxes do not limit total emissions since firms can continue to emit as long as they pay the tax. ETSs, by contrast, involve a fixed quantity or cap on emissions set by the government. Thus, the cost of emissions under an ETS varies depending on the availability of the permits that the participants purchase, which varies based on the supply and demand dynamics of the market (Green 2021). The distinction between carbon taxes and ETSs can become blurred in that the former may incorporate a minimum or floor price for permits that resembles a carbon tax in terms of guaranteeing a minimum price for emissions and adding a measure of price certainty to the system. This overlap demonstrates that the boundaries between these forms of carbon pricing may be flexible in practice depending on the policy objectives and circumstances (Hepburn 2006).

Second, in terms of design and administration, carbon taxes are generally considered easier to implement than ETSs. To begin with, governments have extensive tax collection experience, and implementing a carbon tax follows similar principles. Thus, an administration can set the tax rate based on its policy objectives and desired pricing levels and establish a collection and enforcement system using the existing revenue-collection infrastructure. ETSs are more complex in that they involve a series of steps, from determining the appropriate emissions cap and distributing or auctioning the permits to establishing a platform for tracking, trading, and retiring permits them. Governments may also auction permits for multiple years, thereby impacting future prices within the system. Furthermore, carbon offset programs may be incorporated into carbon-pricing policies for which governments must then develop or approve protocols for offset projects through which emitters invest in emission-reduction activities elsewhere that are equipped with robust monitoring and verification mechanisms. Overall, the administrative complexities associated with ETSs are greater because of the various components involved in their implementation, whereas carbon tax programs can utilize existing infrastructure and experience in tax collection (Green 2021).

Studies comparing the effectiveness of ETSs and carbon taxes have reported contradictory results. For example, Im and Kim (2022) analyze 133 countries from 1990 to 2014 and find that carbon-pricing systems reduce carbon emissions in all of them, though they observe greater effectiveness in higher-income countries. They also find statistically strong evidence that ETSs are more effective in the upper-middle and high-income groups. However, other studies suggest that carbon taxes may be more effective than ETSs because, as mentioned, they provide clear and direct incentives for emitters to reduce their carbon footprints. Thus, the price signal generated by a carbon tax can drive behavioral changes, investments in cleaner technologies, and improvements in energy efficiency (Goulder and Schein 2013). For example, a report by the IMF (2019) shows that the clear signals provided by carbon taxes have been effective in changing behavior so as to reduce emissions in Sweden, Finland, and Denmark. However, the design and implementation of an ETS can be complicated, requiring the establishment of regulatory bodies, monitoring systems, and mechanisms for the distribution of allowances that hamper the administration of the system and the enforcement of sanctions (Aldy 2017). Carbon taxes have been successfully implemented in several jurisdictions. For instance, a carbon tax implemented in Sweden in the early 1990s has contributed to a significant reduction in carbon emissions without limiting economic growth (Bonilla, Coria, and Sterner 2012), and one in the Canadian province of British Columbia has reduced emissions without impeding economic performance and, thus, gained public acceptance (Carattini, Carvalho, and Fankhauser 2018).

Notably, factors such as the overall design, the stringency of the targets, the sectors or industries affected, and the levels of enforcement and compliance can influence the effectiveness of carbon taxes and ETSs. Context-specific factors such as the economic structure, political landscape, and technological capabilities of a region also naturally factor into the effectiveness of these policy instruments. Ultimately, the choice between a carbon tax and an ETS depends on the policymakers' specific goals, the context, and the stakeholders' priorities. Some jurisdictions may opt for carbon taxes to provide a clear price signal and encourage reductions in emissions across all sectors while others may prefer the flexibility and market-based approach of ETSs, especially in sectors with complex emissions profiles. Both types of carbon pricing can contribute to efforts to reduce carbon emissions, and, in either case, the effectiveness of the chosen policy instrument, depending as it does on various factors, should be tailored in its implementation to specific regional contexts and objectives.

3. Data

Following the method of Kysuchy and Norden (2016), we use two search strategies to collect the results from the original studies. First, we search the ISI Web of Knowledge, Google Scholar, Elsevier Science Direct, SSRN, ABI/INFORM, and Emerald computerized databases using the key terms “carbon tax,” “emission trading system (ETS),” “carbon policy,” “carbon pricing,” “CO2 reduction,” and “carbon emission” and variations thereof. Second, as is common in meta-analyses (e.g., Green 2021), we examine the reference sections of all of the articles retrieved in the search and those of prior narrative reviews to identify any studies that we may have overlooked, ending our collection period in July 2022. After the elimination of missing records, both strategies yield a raw sample of 1,018 studies. We search the six databases for more recent or published versions of all unpublished papers and make replacements wherever appropriate.

Next, we select the studies eligible for our meta-analysis on the basis of three criteria, retaining only studies that are (1) written in English, (2) address one or more relationships between one or the other of the two carbon policies and carbon emission performance, and (3) report the sample size and a correlation coefficient or other outcome statistic such as t-value (t), p-value (p), beta coefficient (b), or Chi-square (χ^2) test result since the correlation coefficient value is needed for the analytical procedures (Peterson and Brown 2005; Greene 2008). This search and selection process yields a final sample of 81 studies, 63 published and 18 unpublished. Appendix A presents a complete list.

For each study, we manually collect information relating to the link between the carbon policy and carbon emissions from the various tables, including those in the appendices. This data collection yields a sample of 2,002 estimation results (hereafter "effects"), from a total of 29.2 million unit-period observations. We collect the key characteristics of the selected studies and corresponding country-level variables from the various sources of the publications (e.g., Google Scholar, Web of Science, and the World Bank Country Indicators). Appendix B presents the variables and definitions of them.

Figure 1 presents the distribution of articles by year. The application of our criteria results in the elimination of studies identified in the search that were conducted before 2011. Further, from 2011 to 2018, relatively few studies were conducted on the effectiveness of carbon taxes or ETSs, indicating that researchers either paid less attention to this topic or tended not to view carbon pricing as a critical issue in this period. A significant shift is observable in this regard from 2019 to 2022, during which time the number of studies conducted on this topic increases noticeably. This increased attention from researchers and policymakers suggests a growing recognition of the importance of these mechanisms for reducing carbon emissions and addressing climate change and reducing carbon emissions attributable to the urgency of reducing GHG emissions and addressing climate change on the global agenda and interest generated by the implementation of carbon pricing mechanisms in various countries and regions during this period.

[Insert Figure 1 here]

In Table 1, we report the summary statistics for the studies in our sample, with Panel A presenting its composition. The studies include primarily single-country data, with a significant portion of them, 29 of 81, being focused on China. Among the other single-country studies, 6 focus on Canada, 4 on the USA, 3 on Japan, 3 on Switzerland, 2 on Sweden, 6 without specifically mentioning the country. The sample also includes 28 studies with data from multiple countries, specifically, 14 focusing on the EU countries, 4 focusing on the OECD countries, 1 focusing on Africa, and 9 that develop broader international perspectives. In terms of the developmental status of the countries analyzed, the sample includes 26 studies focusing on developed countries, 32 studies on emerging countries, and 23 studies that use data from both developed and emerging countries. Further, our sample includes 31 studies that use county-level data, 27 studies that use province- or city-level data, 8 that use industry- or sector-level data, and 15 that use firm-, facility-, or plant-level data. In terms of the type of data used, 6 studies in the sample use primary data and 75 use secondary data. Lastly, 33 of the studies focus on carbon taxes, 40 focus on ETSs, and 8 consider the effects of both types of carbon-pricing policies.

Panel B presents the characteristics of the sample. The mean value of the publication year for the 81 studies is 2018, and the mean value of the sample period midyear is 2006, indicating that analyses in our sample, in general, use long time-series data. The mean value of the journal impact factor of 6.8 and the mean value of the citation numbers of 58.3 indicate that the studies in our sample are of relatively high quality. On average, each study involves the analysis of 438 units and covers 7,497.8 observations. As mentioned, 63 of the studies are published and 18 are unpublished, representing 78% and 12% of the sample, respectively. The studies have an average of 25 effect sizes.

[Insert Table 1 here]

4. Empirical Analysis

4.1. Method

Our meta-analysis involves combining individual research findings systematically and quantifying the differences across them. This method is robust in terms of addressing statistical artifacts and obtaining an accurate understanding of the relationship between the variables of interest, even when the results reported in the original studies are not directly comparable. This approach is widely used in the medical sciences and, increasingly, in the social sciences (e.g., Stanley 2001; Kysucky and Norden 2016; Neves and Sequeira 2018; Samba, Van Knippenberg, and Miller 2018; Schweiger, Stettler, Baldauf, and Zamudio 2019; Jacobs and Müller 2020; Ugur, Churchill, and Luong 2020; Kaiser, Lusardi, Menkhoff, and Urban 2022). Researchers conduct meta-analyses to identify systematic patterns of heterogeneity among studies and factors that may contribute to variation in the results and to test hypotheses and theories. Besides, meta-analyses provide comprehensive and reliable assessments of overall effect sizes by combining the data from multiple sources, allowing for more precise and well-informed conclusions. Empirical testing contributes to the analysis and interpretation of research findings. The empirical testing in the present study consists of four primary steps: 1) the literature search and data collection, 2) the computation of comparable effect sizes, 3) the estimation of the magnitude and direction of the true relationship, and 4) an explanation of any systematic heterogeneity. The total variance observed in the results is attributable to the true variance across studies and the sampling error. In meta-analytic procedures, the contribution of each individual result is weighted based on its sampling error to enhance the accuracy of the estimate of the actual relationship. We employ the state-of-the-art meta-analytic methods of Lipsey and Wilson (2001), Borenstein et al. (2009), and Kysucky and Norden (2016).

We use the “effect” as the measure of the magnitude, direction, and significance of the relationship between the carbon-pricing policies and any reductions in carbon emissions. To quantify the effects, we use one discrete measure and two continuous measures. The discrete measure categorizes the reported effects as negative, positive, or non-significant at the 10% significance level to help us identify whether the policies have a favorable, unfavorable, or statistically insignificant impact on carbon emissions reduction.

There are three continuous measures, i.e., the one-tail *p*-value, overall correlation, and Fisher's z-score. The one-tail *p*-value provides a continuous interpretation of the direction and significance of the effect size and is calculated using Edgington's normal curve method based on the contrast of the *p*-value average (Edgington 1972). The values range from 0 to 1, with values approaching 0 indicating a statistically unfavorable impact on carbon emissions reduction and values approaching 1 indicating a statistically favorable impact. This measure complements the discrete measure by providing more nuanced information about the significance and direction of the effects.

The overall correlation (ρ) is the meta-analytic pooled estimate of the random or fixed-effects mean correlations (Lipsey and Wilson 2001; Borenstein et al. 2009) and is based on the partial correlations obtained from the *t*-values of the regression coefficients following the method used by Greene (2008). The continuous Fisher's z-score represents the partial correlation corrected for skewness for each effect size following the method of Borenstein et al. (2009), with positive values indicating a positive relation between the independent and dependent variables and negative values indicating a negative relation. This measure helps us to analyze the heterogeneity in the degree of association between the dimensions of the explanatory variable (i.e., carbon-pricing policies) and the outcomes (i.e., reduced carbon emissions) while accounting for the influence of the other explanatory variables included in the regression models. To mitigate the influence of potential outliers, extreme observations are winsorized at the 1% and 99%.

Utilizing these three sets of measures, we obtain information on the relative significance, direction, and magnitude of the association between the carbon-pricing policies and reductions in carbon emissions. We adopt these effect-size measures, developed by Koetse et al. (2009) and Card et al. (2010), from the field of economics. To enhance the precision of our estimates, we follow Bijmolt and Pieters (2001) and collect a complete set of effects from all the studies in our sample.

4.2. Direction and significance of the effects

To evaluate the direction and significance of the relationship between the carbon-pricing policies and carbon emissions, we estimate the overall discrete and continuous effects for each policy. We are able to report discrete relative frequencies of significantly positive, significantly negative, and non-significant effects and to determine the exact number of individual effect sizes for the various effects of carbon taxes on carbon emissions. For the continuous effects, we calculate the pooled estimate of the overall one-tail *p*-value using Edgington's normal curve method as described above (Edgington 1972).

We report the results in Table 2. As the first row shows, our sample has 857 effect sizes with the available *p*-values extracted from 41 studies of the effect of carbon taxes. A positive sign (+) identifies the positive and significant regression coefficients, which suggest that the carbon taxes have a significantly positive effect in 89 individual effect sizes and that implementing them leads to increases in carbon emissions, which is to say that the effect of the taxes is the opposite of the intent. Conversely, a negative sign (−) identifies the negative and significant coefficients, which suggest that the carbon taxes have a significantly negative effect on the carbon emissions in 400 individual effect sizes and that implementing them leads to a reduction in carbon emissions, which is to say that the taxes have the desired effect. The "ns" notation identifies the 368 non-significant regression coefficients in our sample, which indicates that the relationship between these carbon taxes and carbon emissions is not statistically significant in these individual effect sizes. The column labeled "B/N" reports whether the overall effect of the carbon taxes is "beneficial" (B) and significant at the 1% level. We are consistently able to derive a similar conclusion for the continuous effects. For example, the column labeled "0/1" indicates whether effects are significantly favorable ("1") for reducing carbon emissions at the 10% level.

In the second row of Table 2, we report the effect of the ETSs on carbon emissions. Our sample has 1,135 effect sizes with available *p*-values extracted from the 48 studies about the effect of ETSs. The positive sign (+) identifies the positive and significant regression coefficients, which suggest that the ETSs have a significantly positive effect on carbon emissions in 75 individual effect sizes and that implementing them leads to an increase in carbon emissions, which is to say that the effect of the ETSs is the opposite of the intent. Conversely, the negative sign (−) indicates that the ETSs have a significantly negative effect on carbon emissions in 553 individual effect sizes and that implementing them leads to a reduction in carbon emissions, which is to say that the ETSs have the desired effect. The "ns" notation identifies the 507 non-significant regression coefficients in our sample, which indicates that the relationship between the ETSs and carbon emission is not statistically significant in these individual effect sizes. The column labeled "B/N" reports whether the overall effect of the ETSs on carbon emission reduction is "beneficial" (B) and significant at the 1% level. We are able to derive a similar conclusion for the continuous effects. For example, the column labeled "0/1" indicates whether the effect is significantly favorable ("1") for reducing carbon emissions at the 10% level.

[Insert Table 2 here]

We also estimate the overall pooled effect based on all of the individual effect sizes (817 observations for carbon taxes and 1,134 observations for ETSs) and present the distribution of the continuous one-tail *p*-values in Figure 2. Values approaching 0 represent results with significantly unfavorable effects for reducing carbon emissions at the 10% level while values approaching 1 represent results with significantly favorable effects in this regard at the 10% level, and values in the range of 0.05–0.95 indicate results that are insignificant at the 10% level. The distribution of *p*-values shows that the effects of either carbon-pricing policy on carbon emissions cluster around two extremes, with the frequency of *p*-values near 1 being significantly larger than the frequency of *p*-values near 0. This finding suggests that the implementation of both of these approaches to reducing carbon emissions is associated with reductions in carbon emissions and that their benefits outweigh the drawbacks.

Besides, the findings indicate that 81.80% of the significant effects of the carbon taxes in our sample are beneficial in terms of reducing carbon emissions reduction while 18.20% are not. That is, the implementation of the carbon taxes generally leads to favorable outcomes in terms of reducing carbon emissions, but the reduction effect is not universally beneficial, and certain factors or circumstances may cause the introduction of a carbon tax to result in an increase in carbon emissions. Of the significant effects of the ETSs, 88.00% are beneficial for carbon emissions reduction, whereas 12.00% are not. Thus, the ETSs are generally effective in reducing carbon emissions but, in certain cases, their implementation may have the opposite effect. Overall, our findings suggest that both carbon taxes and ETSs can be effective in reducing carbon emissions.

[Insert Figure 2 here]

4.3. Univariate analysis of the effects

Next, we use meta-analytic techniques similar to those used in prior accounting and finance research (e.g., Edgington 1972; Hunter and Schmidt 2004; Kysuchy and Norden 2016; Lu and Taylor 2016) to estimate the pooled effect size and calculate the overall ρ-estimate for the effect of each carbon policy on carbon emissions. A correlation between the two groups could occur by chance. The likelihood that an effect, such as a correlation seen in the data, can be assessed based on the *p*-value—which represents the probability that a null value is correct—can be influenced by the size of the effect and the size of the sample. Specifically, the probability correlates with the sizes of the effect and of the sample. Thus, the estimation of *p*-

values alone can complicate the interpretation of a single relationship. Since our aim here is both to test the null hypothesis and to determine the precise sizes of the effects, we calculate the effect sizes in our overall effect analysis and univariate analysis. In interpreting these effect sizes, we follow Cohen (1988) and consider ρ-estimates with absolute value less than 0.10 to indicate "small" effect sizes, estimates between 0.10 and 0.25 to indicate "medium" effect sizes, and estimates between 0.25 and 0.40 to indicate "large" effect sizes.

More specifically, to assess the main effect of the carbon policies on carbon emissions, we calculate the weighted correlation (ρ) between the policies and the emissions by weighting the correlations in the eligible studies by sample size and then averaging the studies to account for the sampling error in the estimation. A high absolute value of ρ indicates a strong association between the carbon-policy instrument in question and reductions in carbon emissions. To determine the significance of the correlations between the policies and emissions, we further calculate the 95 percent bootstrapped confidence interval (CI) to provide a more powerful estimate than the traditional CI, for the bootstrapped CI does not require the assumption of a normal distribution of data. We also calculate the z-value to determine whether the overall relationship is significant.

To assess the relative effectiveness of the carbon taxes and ETSs, we perform fixed- and random-effect models based on the assumption that the true effects vary across the studies. This approach is common in the social sciences since studies in this field tend to be significantly heterogeneous and to vary with respect to the empirical strategies and samples used. The random effects model involves the application of a weighting scheme based on the heterogeneity in precision as well as in effect sizes. The fixed-effect model assumes that one true effect size factors into the results of all of the studies in a meta-analysis (hence the designation "fixed") and that sampling error is responsible for any differences in the observed effects. Investigators use the singular (i.e., "effect" rather than "effects") since there is only one true effect.

We report these results in Table 3. For the random-effect model, we find the overall correlation between the carbon taxes and carbon emissions is -0.09, indicating a reduction effect of the taxes. The effect has little economic significance (Cohen 1988). The fact that the 95 percent bootstrapped CI around the mean correlation ranges from -0.099 to -0.091, thus excluding 0, indicates that the effect size is significant and suggests that the implementation of the carbon taxes significantly reduces carbon emissions, but the effect may not be economically material. As the second row in the table shows, the overall correlation between the ETSs and carbon emissions is -0.025, indicating a reduction effect on carbon emissions. The effect has little economic significance. The 95 percent bootstrapped CI around the mean correlation ranges from -0.027 to -0.024, indicating that the effect size is significant and suggesting that the implementation of the ETSs also significantly reduces carbon emissions, but the effect is not material economically.

Next, we compare the magnitude of the ρ-values of the carbon taxes and the ETSs. We find that the weighted correlation between the carbon taxes and carbon emissions is more negative than the one between ETS and carbon emissions. This result suggests that carbon taxes are more effective in reducing carbon emissions than the ETSs. Our results are similar when we use the fixed-effect model.

Overall, our findings suggest that both carbon taxes and ETSs can reduce carbon emissions. However, the magnitude of the reductions is not large. Further, we find that the carbon taxes, possibly because they provide clear and direct incentives for emitters to reduce their carbon footprints, are more effective than the ETSs. Put another way, by imposing a price on each unit of carbon emitted, a carbon tax creates a strong price signal that motivates emitters to take immediate action to reduce their carbon footprint and can lead to behavioral changes as businesses and individuals seek to minimize their carbon tax liabilities by adopting more sustainable practices and technologies. Moreover, the predictable and transparent nature of carbon taxes promotes long-term planning and investment in clean technologies, energy-efficient processes, and, thereby, further reductions in emissions. The direct financial implications of carbon taxes, then, provide tangible motivation for carbon-intensive industries to pursue greener practices actively and support the transition to a low-carbon economy. By contrast, an ETS, being subject to market fluctuations and uncertainties, may be less effective in providing a consistent and strong incentive for emitters to act decisively to reduce their carbon emissions.

[Insert Table 3 here]

4.4. Heterogeneity and publication bias

Next, we investigate the heterogeneity in the effects of the two carbon policies using the Chi-squared (χ^2) and scale-free index (I^2) statistics. A statistically significant χ^2 or an I^2 statistic with a high value suggests that some factors may explain the variations in the effects. We use these statistics to assess the degree of variation and inconsistency among the studies in our analysis.

A potential explanation for the more favorable assessment of the means of the distribution of the effects in the updated data is that the literature is subject to publication bias. Publication bias refers to the potential preference for researchers to report and journals to publish statistically significant results (Brodeur et al. 2016, 2020). Therefore, following Lu and Taylor (2016), we use fail-safe n and *z* values to investigate the possibility of publication bias, which occurs when studies with non-significant or negative results are underrepresented in the literature. For this study, these values help us evaluate the potential impact of the unpublished studies on our results. We calculate the fail-safe sample size n specifically to assess the possibility of publication bias or the "file-drawer" problem, with a higher value suggesting that our results are robust and reliable.

We report the results in Table 4. The χ^2 values are statistically significant for the effects of the carbon taxes and ETSs on carbon emissions, indicating heterogeneity and suggesting that an examination of the key factors which might have an impact on the relationship between the carbon policies and emissions is warranted. The results do not indicate any significant publication bias in the studies that address either carbon taxes or ETSs, as indicated by the large values of fail-safe n and non-significant z values. The absence of publication bias means that our sample of studies provides a balanced representation of the available literature on the relationship between the carbon-reduction policies and carbon emissions. Specifically, the value of Rosenthal's (1979) fail-safe n is 12,915 for the effect of the carbon taxes and 18,440 for the effect of the ETSs, suggesting that it would be necessary to add 12,915 or 18,440 studies to the meta-analysis, respectively, to yield a statistically non-significant overall effect. In other words, these results indicate that publication bias or the file-drawer problem does not contribute to the findings discussed here.

Overall, our results demonstrate the presence of heterogeneity, suggesting that factors such as variation in the designs and methodologies as well as contextual factors may contribute to the diverse effects observed in our analysis. The absence of publication bias, on the other hand, indicates that our findings are not skewed by the selective reporting of significant or positive results. These results thus indicate the need to consider heterogeneity and factors that may influence the effectiveness of the carbon taxes and ETSs.

[Insert Table 4 here]

4.5. Robustness checks

We conduct additional robustness checks to validate further the findings regarding the relative effectiveness of the carbon taxes and ETSs. First, instead of using every individual effect size from each study, we calculate the average effect size per study and then conduct a meta-analytic analysis to obtain the overall weighted correlation (ρ) between the carbon policies and carbon emissions. This approach helps us to capture the overall impact of the carbon taxes and ETSs on carbon emissions at the study level. We perform a second check by excluding the unpublished papers from our analysis to ensure that the findings are based on research that has undergone a rigorous peer-review process, thereby enhancing the reliability and credibility of our results. As a last robustness check, we exclude the studies that use firms, buildings, plants, facilities, installations, and households as the data units to focus on efforts to reduce carbon emissions at the national and regional levels. As Table 5 shows, the results consistently support our initial findings, confirming that both the carbon taxes and the ETSs significantly reduce carbon emissions, with the former being more effective than the latter.

[Insert Table 5 here]

4.6. Heterogeneity analysis

Because we observe heterogeneity in dataset, we explore key factors of the variation in the effects of the carbon-reduction policies. In addition to integrating the results across studies, our meta-analytic procedures identify factors that might contribute to the variation in the relationship between the policies and carbon emissions. In this section, we describe our documentation of the heterogeneity in the effects of the carbon policies from the perspective of country- and industry-level characteristics.

4.6.1. Country characteristics

Prior cross-country studies provide some evidence that the effects of carbon policies on emissions vary across countries and regions (e.g., Lin and Li 2011; Tomáková 2021; Pretis 2022). For example, as discussed, Lin and Li (2011) find that carbon taxes on per capita CO2 reduce emissions in Finland but not in Denmark, Sweden, or the Netherlands because of tax exemptions granted to certain energy-intensive industries and increase emissions in Norway because of the rapid growth in the energy products market. Therefore, we predict that country-level characteristics could influence the effectiveness of carbon policies. Table 6 presents the results of the multivariate meta-regression analysis.

We first examine the variation in the effectiveness of the policies with a series of measures of carbon-policy-environment measures, including pollution, financial development, GDP growth, law enforcement, tax enforcement, and the number of researchers who contribute to each study. We reason that the policies could be either less effective in countries with high pollution levels (*Pollution level*) —because of a lack of public and/or governmental attention to pollution—or more effective—because such countries can easily reduce their emissions from their high starting point. To explore these issues, we collect country-level CO2 emission data from the Climate Watch database. We also predict that the policies could be more effective in countries with greater financial development and stronger GDP growth because they depend less on polluting activities. Based on data from the IMF, we construct a financial development index (*Financial development*) based on the development level of the financial institutions and markets in a given country in terms of depth, access, and efficiency. The value of *Financial development* ranges from 0 to 1, with higher values corresponding to greater financial development. Using national accounts data from the World Bank and the OECD, we calculate *GDP growth* as the annual percentage growth rate of the GDP at market prices based on constant local currency. Furthermore, based on the finding of an inverted U-shaped relationship between policy stringency in the collection of environmental taxes and CO2 emissions in a study by Wolde-Rufael and Mulat-Weldemeskel (2021) of seven emerging economies from 1994 to 2015, we expect the effectiveness of carbon taxes to vary across countries depending on their legal and tax-enforcement systems. Following Brown et al. (2014) and La Porta et al. (1998), we assign to *Legal system* a value of 1 for countries with common law systems and 0 for countries with code law systems. Using data from Ernst and Young Global Transfer Pricing, we calculate *Tax enforcement* as the average score for the six dimensions of the different tax environment following Beuselinck et al. (2015), with higher values corresponding to weaker tax enforcement.

In columns (1) and (2) of Table 6, we present the results of our analysis separately for the carbon taxes and the ETSs, respectively. In column (1), we find that although the effect of the carbon taxes is more pronounced in regions with higher GDP growth rates and financial development, both coefficients are insignificant. In addition, we find other country level factors, including pollution level, law enforcement, tax enforcement, and the number of researchers, also have no significant heterogeneity effect. Our results in column (1) suggest that country-level factors do not significantly contribute to the variation in the impact of carbon taxes on carbon emissions.

In column (2), we find that the effect of the ETSs to be more pronounced in regions with greater financial development, higher GDP growth rates, and less stringent tax enforcement. The fact that the coefficients are significant at the 10% or 1% levels suggests that a strong relationship exists between these factors and the effectiveness of the ETSs. Taken together, these findings suggest that country-level characteristics of financial development, GDP growth rates, and tax enforcement help determine the effectiveness of ETSs, but not carbon taxes.

Next, we compare the effectiveness of the carbon policies across regions. To do so, we distinguish Japan, the United States, Europe, Canada, Asia excluding Japan and China, and China. We use Japan as the benchmark as it has adopted both carbon tax and ETS. Columns (3) and (4) in Table 6 report the results separately for the carbon taxes and ETSs, respectively. We find the effect of the carbon taxes to be stronger in Asia (excluding Japan) than in the United States, Europe, and Canada. Notably, though, this result does not imply that the effect of the carbon taxes is weaker in these regions—except in China, where the effect is, in fact, weak—but that, *ceteris paribus*, the benefits of reducing carbon emissions are relatively low in these regions. Similarly, we find the effect of the ETSs to be stronger in the United States than in China and Europe and to be weak in Asia and Canada. We conclude that the effectiveness of the ETSs varies across regions, with those in the USA exhibiting a stronger effect than those in China and Europe.

Overall, the findings presented here highlight the regional variations in the effectiveness of the carbon taxes and ETSs and underscore the need for region-specific policy approaches and tailored strategies to address carbon emissions effectively.

[Insert Table 6 here]

4.6.2. Industry characteristics and sources of carbon emissions

Factors such as the elasticity of demand for carbon-intensive products, the availability of alternative energy sources, regulatory frameworks, and complementary policies can also influence the effectiveness of carbon taxes. For example, Pretis (2022) shows that the impact of carbon taxes varies across sectors. We examine the influence of CO2-intensive industries and various sources of carbon emissions on the effectiveness of carbon-pricing policies further by considering whether certain industries or specific sources of emissions have a greater impact on the effectiveness of carbon-pricing policies.

The results, reported in Table 7, indicate that both carbon taxes and ETSs have a pronounced effect in reducing carbon emissions by CO2-intensive industries, suggesting that these industries, which significantly contribute to emissions, are especially responsive to carbon policy measures. In other words, the implementation of carbon taxes and ETSs in these industries may lead to greater reductions in carbon emissions than in other industries. Furthermore, our findings indicate that the effectiveness of carbon taxes varies depending on the measurement of the carbon emissions, with stronger effects when emissions are measured by fossil fuels use than other measure methods, such as electricity use, coal use, and direct CO2 emission. The implication is not that carbon taxes are less effective in reducing the emissions from such resources but that, in these cases, the benefits of reducing carbon emissions may be relatively fewer. The effectiveness of ETS varies depending on the measurement of the carbon emissions. The results of this study indicate that the ETSs have a more pronounced effect in reducing the carbon emissions that originate from the electricity sector rather than from other sources such as energy use, coal use, CO2, and fossil fuels use, which is to say that implementing an ETS in the electricity sector can significantly reduce carbon emissions. These findings demonstrate the importance of considering the specific characteristics of industries and the measurement of carbon emissions when designing and implementing carbon-pricing policies. Tailoring policy measures to target CO2-intensive industries and focusing on the sources of emissions that have the greatest potential for reduction can enhance the effectiveness of carbon-pricing policies and reductions in emissions.

[Insert Table 7 here]

5. Conclusions and Policy Implications

5.1. Conclusions

In this paper, we conduct the meta-analysis to provide an overview of and explain the heterogeneity in the literature on the effectiveness of carbon-pricing policies, specifically, carbon taxes and ETSs, in reducing carbon emissions. We find that the introduction of these policies effectively reduces carbon emissions and that carbon taxes appear to be more effective than ETSs. Further, both carbon taxes and ETSs exhibit heterogeneity in their effects as indicated by variation across the studies that are likely attributable to variation in their designs and methodologies and in contextual factors. Thus, carbon taxes are more effective in Asia (excluding Japan) than in the USA, Europe, and Canada, while ETSs are more effective in the

USA than in China and Europe. These regional differences indicate the need for tailored policy approaches and strategies to reduce carbon emissions. Moreover, our findings suggest that country-level characteristics such as financial development, the GDP growth rate, and tax enforcement can influence the effectiveness of carbon-pricing policies, particularly ETSs. Our findings show, in addition, that the carbon taxes and ETSs have stronger effects in reducing emissions in CO2-intensive industries, which, in turn, demonstrate greater responsiveness to them. The effectiveness of these policies also varies depending on the sources of carbon emissions, with stronger effects observed for emissions derived from fossil fuels and the electricity sector.

5.2. Practical implications

The findings of this study have practical implications for policymakers, government officials, environmentalists, regulators, and other stakeholders involved in formulating strategies to address carbon emissions and achieve carbon neutrality targets. We provide evidence that carbon-pricing policies can effectively reduce carbon emissions and, therefore, merit consideration as key instruments in strategies for mitigating climate change. These policy instruments generally lead to positive outcomes in terms of reducing carbon emissions and the achievement of sustainable development goals, particularly carbon-neutrality targets. Our results also show heterogeneity in terms of the effectiveness of the carbon-pricing policies, indicating the need to recognize the importance of specific factors and contexts, such as local economic and industrial structures, political commitment and support, technological advancements, and the availability of alternative energy sources, when designing and implementing them. Overall, we find that carbon taxes tend to be more effective than ETSs, so policymakers may wish to focus on the former in efforts to achieve carbon neutrality goals. At the same time, it is important to acknowledge the heterogeneity in the effectiveness of both carbon taxes and ETSs attributable to contextual factors.

Likewise, our findings highlight regional variation in the effectiveness of carbon-pricing policies. Accordingly, policymakers should adopt approaches and strategies to address carbon emissions that are tailored to suit regional characteristics and specific challenges, for instance, by taking into account variations in economic structures, energy systems, and political landscapes. The findings presented here also suggest that certain country-level characteristics, such as financial development, GDP growth rates, and tax enforcement, can enhance the effectiveness of carbon-pricing policies, particularly ETSs, so policymakers should also consider these characteristics and align policy design with countries' unique socio-economic contexts. Our finding that carbon taxes and ETSs have stronger effects in CO2-intensive industries indicates that policymakers should prioritize these industries when formulating strategies and setting targets for reductions in carbon emissions. Industry-and sector-specific carbon-pricing policies and tailored regulations can incentivize emission reductions and foster innovation in carbon-intensive sectors. Because the effectiveness of these policies also varies depending on the source of carbon emissions, policymakers should consider, for instance, using carbon taxes to reduce emissions from fossil fuels and ETSs to reduce emissions from the electricity sector. A nuanced approach that accounts for the specific sources of emissions, then, can help to optimize the impact of carbon-pricing policies.

Policymakers should likewise establish robust monitoring and evaluation mechanisms to ensure the long-term effectiveness and sustainability of carbon-pricing policies. Regular assessments serve to track the progress and impact of these policies on carbon emission reduction and identify areas for improvement so as to refine policies based on real-world experience and emerging knowledge. By adopting an adaptive approach and learning from the implementation experience, policymakers can analyze and modify policies to suit the local conditions, taking into account potential impacts and trade-offs. The feedback and lessons learned from implementation can help to fine-tune policies, so policymakers should actively engage with the full range of stakeholders, including businesses, environmental organizations, and communities, to foster the acceptance of policies, enhance their effectiveness, and address any unintended consequences. Since climate change is a global problem, policymakers should promote international cooperation and knowledge-sharing platforms, for the sharing of experiences, best practices, and lessons learned from successful case studies can facilitate the development and implementation of effective carbon-pricing policies in jurisdictions worldwide.

Overall, our study demonstrates the potential of carbon-pricing policies to address the environmental challenges associated with climate change and promote sustainability. However, careful consideration of the specific contexts and the factors influencing effectiveness and continuous monitoring, evaluation, and refinement of policies are necessary to ensure the long-term effectiveness of these policies. Policymakers should, then, analyze and modify policies to suit the local conditions, consider potential impacts and trade-offs, and incorporate feedback and lessons learned to achieve the desired emission-reduction goals, which ultimately contribute to the attainment of carbon neutrality targets.

In summary, this meta-analysis provides insight into carbon-pricing policies to reduce emissions, which is invaluable for policymakers and other stakeholders in formulating policies to achieve carbon neutrality targets. The findings of this study highlight the key role that carbon-pricing policies can play in the global effort to achieve carbon neutrality by reducing emissions across various sectors and regions, ultimately contributing to a more sustainable and climate-resilient future. Through a comprehensive understanding of the relative effectiveness of carbon taxes and ETSs, tailoring policies to regional and sectoral contexts, and aligning these policies with sustainable development goals, environmental regulators and policymakers can make informed decisions to expedite progress towards carbon neutrality.

6. Limitations of This Study and Directions for Future Research

Finally, we acknowledge that this study is subject to certain limitations that merit consideration in follow-up research studies. For instance, while we focus on the effectiveness carbon-pricing policies on carbon emissions, which contribute greatly to climate change, the scope of the present study is insufficient to provide a comprehensive account of the broader impacts of these policies on society and the environment. Climate change is a complex and dynamic phenomenon involving numerous interconnected factors, so other environmental and social considerations may also be important when evaluating the overall impact of carbon-pricing policies. The potential social impacts, such as how policies affect vulnerable populations, economic competitiveness, and employment dynamics in carbon-intensive sectors, are of particular significance for crafting equitable and effective climate policies.

Moreover, additional factors not considered in the analysis may influence the observed outcomes described here, such as technological advances, political stability, public awareness, and concurrent environmental policies. Any and all of these factors can influence the effectiveness of carbon-pricing policies. Lastly, our focus is on CO2-intensive industries, and an assessment of the effects of policies across other industries and the potential trade-offs and synergies would provide a more comprehensive perspective.

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Appendix A Studies Included in the Meta-Analysis

ID	Author(s)	Title	Policy	Year	Publication	No. of effects	No. of obs.	No. of citations	Journal IF
1	Alexandersson	The effect of environmental policies on CO_2 emissions- using the environmental policy stringency index	carbon tax	2020	Unpublished	8	335	1	NA
2	Alper	Analysis of carbon tax on selected European countries: does carbon tax reduce emissions	carbon tax	2018	Applied Economics and Finance	2	378	8	0.3
3	Anderson and Di Maria	Abatement and allocation in the pilot phase of the EU ETS	ETS	2011	Environmental and Resource Economics	2	273	257	4.042
4	Andersson	Carbon tax and CO2 emissions: Sweden as a case study	carbon tax	2019	American Economic Journal: Economic Policy	18	42	177	7.81
5	Antweiler and Gulati	Frugal cars or frugal drivers? How carbon and fuel taxes influence the choice and use of cars	carbon tax	2016	Unpublished	24	483	34	NA
6	Arcila and Baker	Evaluating carbon tax policy: a methodological reassessment of a natural experiment	carbon tax	2022	Energy Economics	4	39	0	9.489
7	Arimura and Abe	The impact of the Tokyo emissions trading scheme on office buildings: what factor contributed to the emission reduction?	ETS	2021	Environmental Economics and Policy Studies	6	1192	33	1.564
8	Bashir, Ma, Shahbaz and Jiao	The nexus between environmental tax and carbon emissions with the roles of environmental technology and financial development	carbon tax	2020	PLoS One	8	602	37	3.24
9	Best, Burke and Jotzo	Carbon pricing efficacy: cross-country evidence	carbon tax and ETS	2020	Environmental and Resource Economics	24	222	67	4.042
10	Borghesi, Cainelli and Mazzanti	Linking emission trading to environmental innovation: evidence from the Italian manufacturing industry	ETS	2015	Research Policy	10	3561	275	11.442
11	Bretscher and Grieg	Exiting the fossil world: the effects of fuel taxation in the UK	carbon tax	2020	Unpublished	1	420	11	NA
12	Cao, Ho, Ma and Teng	When carbon emission trading meets a regulated industry: evidence from the electricity sector of China	ETS	2021	Journal of Public Economics	118	4107	25	6.231
13	Chan and Morrow	Unintended consequences of cap-and-trade? evidence from the Regional Greenhouse Gas Initiative	ETS	2019	Energy Economics	54	79341	24	9.489
14	Chen, Shi and Wang	Carbon emission curbing effects and influencing mechanisms of China's Emission Trading Scheme: the mediating roles of technique effect, composition effect and allocation effect	ETS	2020	Journal of Cleaner Production	54	178	49	11.016
15	Davis and Kilian	Estimating the effect of a gasoline tax on carbon emissions	carbon tax	2011	Journal of Applied Econometrics	14	3486	248	3.487

16	Dechezleprêtre, Nachtigall and Venmans	The joint impact of the European Union emissions trading system on carbon emissions and economic performance	ETS	2018	Unpublished	49	1485	86	NA
17	Dellstig	The effect of the Swedish carbon tax on household and industry emissions	carbon tax and ETS	2019	Unpublished	8	28	1	NA
18	Dong, Dai, Zhang, Zhang and Long	Can a carbon emission trading scheme generate the Porter effect? evidence from pilot areas in China	ETS	2019	Science of the Total Environment	2	300	131	10.237
19	Dussaux	The joint effects of energy prices and carbon tax on environmental and economic performance: evidence from the French manufacturing sector	carbon tax and ETS	2020	Unpublished	186	43151	18	NA
20	Fauceglia, Müller, Leu and Betz	How do firms respond to a rising carbon tax?	carbon tax	2020	Unpublished	88	27832	0	NA
21	Fell and Maniloff	Leakage in regional environmental policy: the case of the regional greenhouse gas initiative	ETS	2018	Journal of Environmental Economics and Management	36	30649 9	91	7.346
22	Francescutto and Mathys	The effect of the swiss co2 levy on heating fuel demand of private real estate owners	carbon tax	2022	Energies	64	2291	0	3.333
23	Ganda and Garidzirai	The environmental influence of tax regimes in selected European union economies	carbon tax	2021	Green Computing Technologies and Computing Industry in 2021	12	217	2	NA
24	Gao, Li, Xue and Liu	Evaluation of effectiveness of China's carbon emissions trading scheme in carbon mitigation	ETS	2020	Energy Economics	28	8487	90	9.489
25	Ghazouani, Jebli and Shahzad	Impacts of environmental taxes and technologies on greenhouse gas emissions: contextual evidence from leading emitter European countries	carbon tax	2021	Environmental Science and Pollution Research	4	225	32	5.053
26	Hájek, Zimmermannová, Helman and Rozenský	Analysis of carbon tax efficiency in energy industries of selected EU countries	carbon tax	2019	Energy Policy	1	43	64	7.88
27	Hu, Ren, Wang and Chen	Can carbon emission trading scheme achieve energy conservation and emission reduction? evidence from the industrial sector in China	ETS	2020	Energy Economics	24	2559	144	9.489
28	Huang, Shen, Miao and Zhang	The effects of emission trading scheme on industrial output and air pollution emissions under city heterogeneity in China	ETS	2021	Journal of Cleaner Production	4	2973	11	11.016
29	Im and Kim	Carbon tax or emission trading scheme: which is better to reduce carbon emission?	carbon tax and ETS	2022	Unpublished	4	1403	0	NA

30	Islam	Emissions trading vs. carbon tax: what gets us closer to a zero emissions future? lessons from European implementations	carbon tax	2017	Unpublished	1	270	0	NA
31	Jeffrey and Perkins	The association between energy taxation, participation in an emissions trading system, and the intensity of carbon dioxide emissions in the European Union	carbon tax and ETS	2015	The International Journal of Accounting	6	378	24	5.698
32	Kim, Han and Moon	The empirical effects of a gasoline tax on CO2 emissions reductions from transportation sector in Korea	carbon tax	2011	Energy Policy	2	1122	47	7.88
33	Kokotović, Kurečić and Mjeda	Accomplishing the sustainable development goal 13– climate action and the role of the European Union	carbon tax	2019	Interdisciplinary Description of Complex Systems: INDECS	3	21	5	1.948
34	Kotnik, Maja and Škulj	The effect of taxation on greenhouse gas emissions	carbon tax	2014	Transylvanian Review of Administrative Sciences	6	227	11	0.913
35	Lin and Li	The effect of carbon tax on per capita CO2 emissions	carbon tax	2011	Energy policy	10	153	445	7.88
36	Ma, Yan, Ren and Ren	Can China's carbon emissions trading scheme achieve a double dividend?	ETS	2022	Environmental Science and Pollution Research	20	326	2	5.053
37	McCaw	Carbon policy implementation: a country-level analysis of carbon tax vs. cap and trade	carbon tax and ETS	2021	Unpublished	8	675	0	NA
38	Metcalf	On the economics of a carbon tax for the United States	carbon tax	2019	Brookings Papers on Economic Activity	10	297	85	10.962
39	Miller and Vela	Are environmentally related taxes effective?	carbon tax	2013	Unpublished	37	106	58	NA
40	Morley	Empirical evidence on the effectiveness of environmental taxes	carbon tax	2012	Applied Economics Letters	8	300	97	1.215
41	Mortha, Taghizadeh-Hesary and Vo	The impact of a carbon tax implementation on non-CO2 gas emissions: the case of Japan	carbon tax	2021	Australasian Journal of Environmental Management	128	1175	4	2.033
42	Murray and Maniloff	Why have greenhouse emissions in RGGI states declined? An econometric attribution to economic, energy market, and policy factors	ETS	2015	Energy Economics	5	1104	139	9.489
43	Ott and Weber	The impact of CO2 taxation on Swiss households' heating demand	carbon tax	2018	Unpublished	14	1211	3	NA
44	Peng, Qi and Cui	The environmental and economic effects of the carbon emissions trading scheme in China: The role of alternative allowance allocation	ETS	2021	Sustainable Production and Consumption	36	6768	19	8.424
45	Perez Alvarado	Culture, carbon pricing and its impacts on CO2 emissions and economic growth	carbon tax and ETS	2018	Unpublished	3	49	0	NA
46	Petrick and Wagner	The impact of carbon trading on industry: evidence from German manufacturing firms	ETS	2014	Unpublished	12	26180	163	NA

47	Pretis	Does a carbon tax reduce CO2 emissions? evidence from British Columbia	carbon tax	2022	Environmental and Resource Economics	24	13883	26	4.042
48	Qi, Cheng and Cui	Environmental and economic effects of China's carbon market pilots: empirical evidence based on a DID model	ETS	2021	Journal of Cleaner Production	48	263	27	11.016
49	Ren, Jiang, Ma, Liu and Chen	Will tax burden be a stumbling block to carbon-emission reduction? evidence from OECD countries	carbon tax	2021	Journal of Systems Science and Information	62	504	1	2.508
50	Rivers and Schaufele	Salience of carbon tax in the gasoline market	carbon tax	2015	Journal of Environmental Economics and management	4	2532	209	7.346
51	Runst and Thonipara	Dosis facit effectum why the size of the carbon tax matters: evidence from the Swedish residential sector	carbon tax	2020	Energy Economics	45	228	24	9.489
52	Sæther	Climate policy choices: an empirical study of the effects on the OECD and BRICS power sector emission intensity	ETS	2021	Economic Analysis and Policy	2	659	5	3.636
53	SARIGÜL and TOPCU	The impact of environmental taxes on carbon dioxide emissions in Turkey	carbon tax	2021	International Journal of Business and Economic Studies	2	22	1	0.712
54	Shen, Tang and Zeng	Does China's carbon emission trading reduce carbon emissions? evidence from listed firms	ETS	2020	Energy for Sustainable Development	33	1624	24	6.017
55	Tang, Zhou, Liang and Zhou	The effectiveness and heterogeneity of carbon emissions trading scheme in China	ETS	2021	Environmental Science and Pollution Research	7	2080	19	5.053
56	Tomášková	The impact of the EU ETS in the Czech Republic	ETS	2021	Unpublished	114	4435	0	NA
57	Van den Tempel Almaas and Hillgren	Carbon tax efficiency: what elevates it, and what undermines it?	carbon tax	2021	Unpublished	22	646	0	NA
58	Wakabayashi and Kimura	The impact of the Tokyo Metropolitan Emissions Trading Scheme on reducing greenhouse gas emissions: findings from a facility-based study	ETS	2018	Climate Policy	6	23763	33	5.906
59	Wang, Chen, Wu and Nie	Can a carbon trading system promote the transformation of a low-carbon economy under the framework of the porter hypothesis? – empirical analysis based on the PSM-DID method	ETS	2019	Energy Policy	8	510	143	7.88
60	Wang, Liao, Xu and Malik	The impact of foreign direct investment on China's carbon emissions through energy intensity and emissions trading system	ETS	2021	Energy Economics	6	360	33	9.489
61	Wang, Khurshid, Qayyum and Calin	The role of green innovations, environmental policies and carbon tax in achieving the sustainable development goals of carbon neutrality	carbon tax	2022	Environmental Science and Pollution Research	4	285	5	5.053

62	Wang, Liang, Cheng, Li and Zhang	Emission reduction benefits and economic benefits of China’s pilot policy on carbon emission trading system	ETS	2022	(OA) Computational Intelligence and Neuroscience 2022	29	257	0	3.877
63	Wen, Hu, Li, Liu, Shi, Ewing and Ma	Does China’s carbon emissions trading scheme really work? a case study of the hubei pilot	ETS	2020	Journal of Cleaner Production	16	200	16	11.016
64	Wolde-Rufael and Mulat-Weldemeskel	Do environmental taxes and environmental stringency policies reduce CO2 emissions? evidence from 7 emerging economies	carbon tax	2021	Environmental Science and Pollution Research	18	154	28	5.053
65	Xuan, Ma and Shang	Can China’s policy of carbon emission trading promote carbon emission reduction?	ETS	2020	Journal of cleaner production	21	510	80	11.016
66	Yang, Jiang and Pan	Does China's carbon emission trading policy have an employment double dividend and a Porter effect?	ETS	2020	Energy Policy	8	233	71	7.88
67	Yi, Bai, Yang, Li and Wang	Evaluation on the effectiveness of China’s pilot carbon market policy	ETS	2020	Journal of Cleaner Production	38	104	34	11.016
68	Yiadom and Mensah	Environmental risk, FDI and tax reforms: why we must worry	carbon tax	2021	African Journal of Economic and Management Studies	1	1440	0	1.969
69	Yu, Hao, Cai, Sun and Zhang	Does emission trading system achieve the win-win of carbon emission reduction and financial performance improvement? – evidence from Chinese A-share listed firms in industrial sector	ETS	2022	Journal of Cleaner Production	5	894	10	11.016
70	Zhang and Zhang	Estimating the impacts of emissions trading scheme on low-carbon development	ETS	2019	Journal of Cleaner Production	56	300	46	11.016
71	Zhang, Peng, Ma and Shen	Can environmental innovation facilitate carbon emissions reduction? evidence from China	ETS	2017	Energy Policy	4	390	407	7.88
72	Zhang, Zhang and Yu	Carbon mitigation effects and potential cost savings from carbon emissions trading in China's regional industry	ETS	2019	Technological Forecasting and Social Change	12	300	45	10.403
73	Zhang, Duan and Zhang	Analysis of the impact of China’s emissions trading scheme on reducing carbon emissions	ETS	2019	Energy Procedia	8	7904	10	2.63
74	Zhang, Duan and Deng	Have China's pilot emissions trading schemes promoted carbon emission reductions? – the evidence from industrial sub-sectors at the provincial level	ETS	2019	Journal of Cleaner Production	56	1640	65	11.016
75	Zhang, Li, Li and Guo	Emission reduction effect and carbon market efficiency of carbon emissions trading policy in China	ETS	2020	Energy	1	270	99	8.234
76	Zhang, Li, Luo and Gao	The effect of emission trading policy on carbon emission reduction: evidence from an integrated study of pilot regions in China	ETS	2020	Journal of Cleaner Production	16	852	68	11.016

77	Zhang, Zhang, Li, Li and Choi	Has China's emission trading system achieved the development of a low-carbon economy in high-emission industrial subsectors?	ETS	2020	Sustainability	11	3438	10	4.089
78	Zhang, Wang, Hao and Liu	Shooting two hawks with one arrow: could China's emission trading scheme promote green development efficiency and regional carbon equality?	ETS	2021	Energy Economics	34	910	42	9.489
79	Zheng and Pearson	Environmental policies analysis for CO2 emission reduction: evidence across countries 1980-2014	carbon tax and ETS	2019	Unpublished	23	864	0	NA
80	Zhou, Zhang, Song and Wang	How does emission trading reduce China's carbon intensity? an exploration using a decomposition and difference-in-differences approach	ETS	2019	Science of the total environment	18	494	122	10.237
81	Zubair	Impact of the BC carbon tax on sectoral GDP and emissions	carbon tax	2013	Unpublished	53	150	0	NA

Appendix B Variable Definitions

Meta-analytic effect sizes

Discrete measure of significance: This variable classifies reported effects from the studies into positive, negative, and nonsignificant ones at the 10% significance level. Alternatively, the variable classifies effects into significant positive and significant negative at the 10% significance level. Significance is derived directly from the reported regression statistics. Source: sample studies

One-tail p-value: A continuous direction and the significance of all of the effect size. Values range from 0 to 1 where values approaching 0 are significantly unfavourable to carbon emission reduction, but values approaching 1 are significantly favourable. One-tail *p*-value is derived from the significance statistics derived from significance statistics reported in a study. If only limited information is provided, such as star indication of the level of significance, we collect the most conservative significance measure (e.g., for significance at > 10% confidence level we code the effect as significant at 10% confidence level). If the effect is in the direction of the hypothesis that the carbon policy is beneficial to carbon emission reduction (i.e., the carbon policy has an association with lower CO2 emission, energy consumption, electricity uses and so on), then the one-tail p-value is defined as p1 = 1 – (p2/2). If the effect is in the opposite direction, then p1 = (p2/2). In this calculation p1 is the one-tail *p*-value and p2 is the two-tail *p*-value reported in papers or derived from significance statistics. For the overall effect size, we apply Edgington's (1972) method to calculate a one-tail *p*-value that indicates the pooled estimate of the significance and the direction of the overall true effect. Source: sample studies

Partial correlation: Partial correlations are obtained directly from sample studies. Correlation coefficients r are typically used in meta-analyses because these are easy to understand and interpret. If no correlation table is presented, we use regression statistics following Greene (2008, Chap. 3): $r = \sqrt{t^2/(t^2 + df)}$, where r is the partial correlation between variables y (dependent variable) and z (independent variable), t is the t-statistic associated with the z coefficient, and df is the degrees of freedom. Furthermore, if the standardized regression coefficient is presented: $r = 0.98\times\beta + 0.05\times\lambda$ (Peterson and Brown, 2005), where β is standardized regression coefficient and λ is indicator variable equal to 1 when $\beta\geq0$ and to 0 when $\beta<0$. Source: sample studies

Fisher's z-score: Partial correlation corrected for skewness. Correction for skewness follows from Borenstein et al. (2009). Positive Fisher's z-scores indicate a positive relation between the carbon policy and carbon emission, negative Fisher's z-scores indicate a negative relation. Source: sample studies

Industry proxy

CO2-intensive industry: Equals 1 if the sample data set is from CO2-intensive industry, including electricity, transport, manufacturing, and agriculture, 0 otherwise. Source: Our World in Data

Carbon emission proxies

CO2: Carbon dioxide emission. Source: studies collected

Electricity: Electricity use. Source: studies collected

Energy: Energy use. Source: studies collected

Fossil fuel: Fossil fuel use. Source: studies collected

Coal: Coal consumption. Source: studies collected

Other: Carbon emission measured by other variables, such as greenhouse gas emission, oil use, or gas consumption. Source: studies collected

Country-level carbon policy environment

We calculate country-level variables for each study, country, and sampling window as equally weighted averages of those country-year observations that are available in our data sets within the sample period of the study. If study observations fall into time periods in which country-level series are available but no time overlap exists between the original sample period and the available country indicator, we use the closest available country-year observation.

Financial development: The index summarizes how developed financial institutions and financial markets are in terms of their depth, access, and efficiency. Values range from 0 to 1, with higher values corresponding to higher financial development. Source: International Monetary Fund

Pollution level: Carbon dioxide emission (Gt), which stem from the burning of fossil fuels and the manufacture of cement. Source: Climate Watch. 2020. GHG Emissions. Washington, DC: World Resources Institute.

GDP growth: Annual percentage growth rate of GDP at market prices based on constant local currency. Source: World Bank national accounts data, and OECD National Accounts data files.

Legal system: Equals 1 for common law, 0 for code law. Source: La Porta et al. (1998) and Brown et al. (2014).

Government effectiveness: Government effectiveness captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.

Values range from -2.5 to 2.5, with higher values corresponding to higher government effectiveness. Source: World Bank, World Governance Indicators

Tax enforcement: The average score on the six different tax environment dimensions following Beuselinck et al. (2015). Higher values correspond to weaker tax enforcement. Source: Ernst & Young Global Transfer Pricing Reference Guides and Keller and Schanz (2013).

Population: Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship. Source: World Bank, World Development Indicators

No. of researchers: The number of researchers engaged in Research &Development (R&D), expressed as per billion. Source: UNESCO Institute for Statistics

Publication variables

Ln no. of observations: Logarithm of number of observations for each regression specification. Source: own data set

Research method: Equals 1 if the study uses DID model and 0 otherwise. Source: own data set

Published: Equals 1 if the study appears in a refereed journal and 0 otherwise. Source: own data set

Subsample: Equals 1 if the effect size is not derived from the main analysis in the original study. Source: own data set

Publication year: The year of the publication. If the paper is available online first, the year of the online publication is used. Source: own data set

No. of citations: Number of citations is obtained from Google Scholar for each paper. Source: Google Scholar

No. of effects: Number of effect sizes for each study. Source: own data set

Median year: The median year of the sampling window. Source: own data set

Data type: Equals 1 if the sample data type is panel data and 0 otherwise. Source: own data set

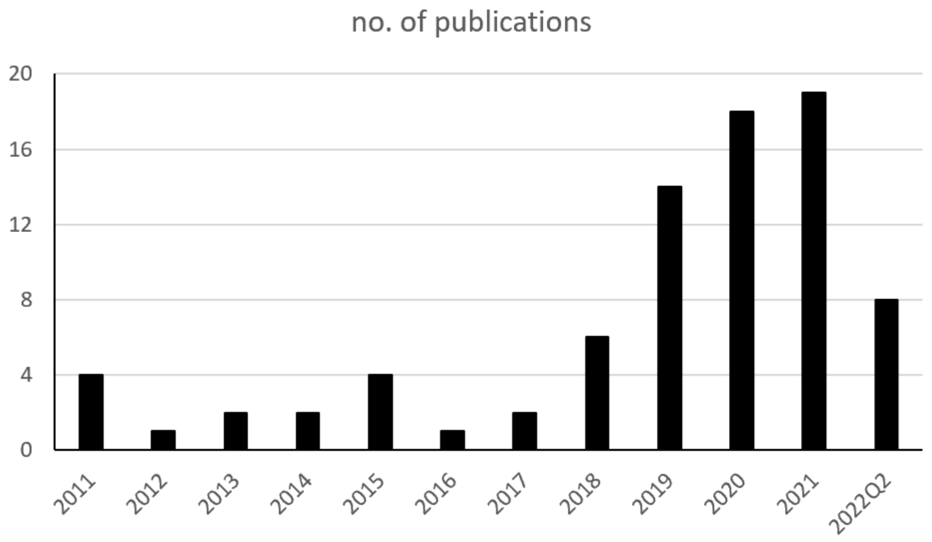
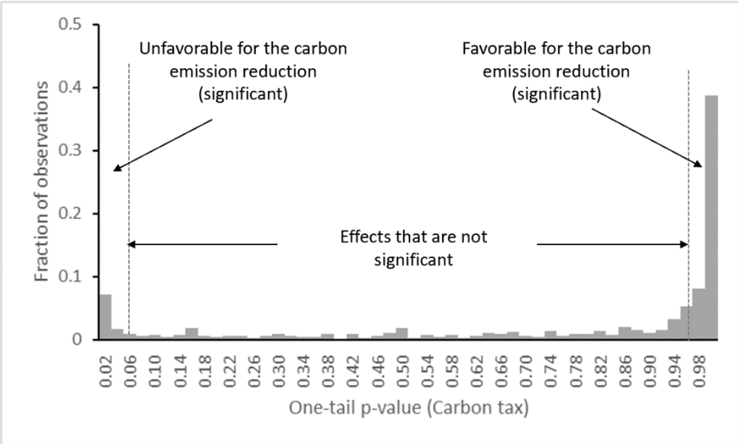


Figure 1 Number of journal articles used in our meta analysis per year (Source: own data set)



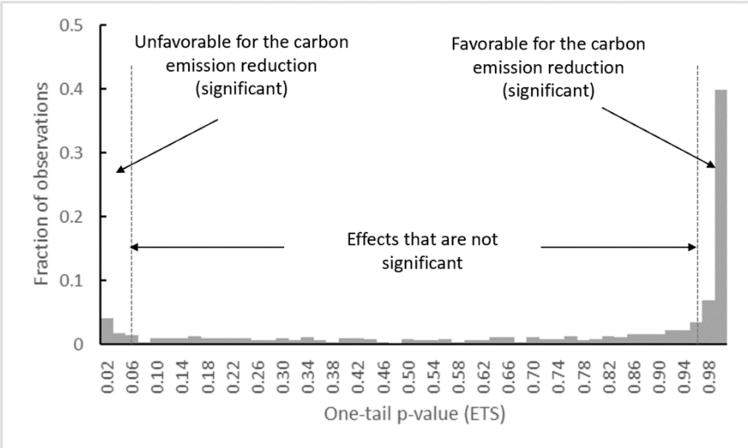


Figure 2 Distribution of the One-Tail *p*-Values

Notes. The two figures show the frequency distribution of one-tail p-values from all selected studies. Values approaching 0 represent results with significantly adverse effects for carbon emission reductions at the 10% level; values approaching 1 represent results with significantly beneficial effects for carbon emission reductions at the 10% level. Values in the range of 0.05-0.95 indicate results for the carbon emission reductions that are not significant at the 10% level. The distributions are based on the total number of 817 and 1,134 observations, respectively.

Table 1 Summary Statistics of Studies in the Sample

Panel A. Sample composition (number of studies)

Publication status		Region			Development status		Data unit		Research topic		Focus on carbon policy	
Published studies	63	Single country	China	29	Developed	26	Country	31	Carbon tax	33	Primary	6
Unpublished studies	18		Canada	6	Emerging	32	Province/City	27	ETS	40	Secondary	75
			USA	4	Both	23	Industry/Sector	8	Both	8		
			Japan	3			Firm/Facility/Plant	15				
			Switzerland	3								
			Sweden	2								
			other	6								
		Multiple countries	EU	14								
			OECD	4								
			Africa	1								
			International	9								
Total	81			81		81		81		81		81

Panel B. Sample characteristics

	Mean	Median	Min	Max	Std. dev.
Publication year	2018.877	2020	2011	2022	2.913
Sample period midyear	2006.608	2008.25	1989.5	2015.5	5.637
Journal impact factor	6.847	7.845	0.3	11.442	3.399
No. of citations	58.284	26	0	445	86.17
Unit count	438.156	30	1	7763	1474.449
Observation count	7497.8	504	21	306000	35369.465
Publication status	0.78	1	0	1	0.41
No. of effects	24.457	12	1	186	32.382

Notes. This table summarizes the characteristics of the selected studies. A study is denoted as published if it appears in a refereed journal. The region relates to the geography of the data sample in each paper. The development status of countries is based on the World Bank development classification in the median sampling year. The data unit represents a study's unit of analysis. The research topic denotes a paper's research content, including carbon tax, ETS and both of them. The focus on carbon policy denotes whether a study uses carbon tax or ETS proxies as the primary explanatory variables in the empirical design. If carbon tax or ETS proxies serve as control variables, then a paper is designated as secondary. The journal's impact factor is from the Journal Citation Report by Thomson Reuters for the year of the publication and is reported only for published studies. The number of citations is obtained from Google Scholar. The unit count is the total number of unique data units included in each study. The observation count is the number of unique unit-period observations approximated as the maximum number of observations in any regression specification within each study. Publication status denotes whether a study is published, which equals 1 if the study appears in a refereed journal and 0 otherwise. The number of effects is the number of effect sizes of the studies entering in our meta-analysis.

Table 2 The Effects of Carbon Policies on Carbon Emissions

			Discrete Effects					Continuous Effects		
			Coeff. sign					One-tail *p*-value		
Relationship	n1	n2	+	-	ns		B/N	0/1		B/N
carbon tax → carbon emission	41	857	89	400	368	***	B	1	***	B
ETS→ carbon emission	48	1135	75	553	507	***	B	1	***	B

Notes. This table report overall discrete and continuous effect sizes for the effect of carbon policies (i.e., carbon tax and ETS) on carbon emissions. n1 is the number of studies; n2 is the number of total effect sizes; In each relationship between the carbon policy and carbon emission, (+) denotes positive and significant correlation or regression coefficients, (-) denotes negative and significant coefficients, and (ns) denotes coefficients that are not statistically significant in the original studies at the 10% level; *, **, *** indicate significance according to a two-tail binomial sign test at the 10%, 5%, and 1% levels, respectively. Indicator "B" ("N") denotes significant pooled effects that are beneficial (anti-beneficial) to the carbon emission reduction at the 10% level. For continuous effects, the pooled estimate of the overall one-tail *p*-value is calculated using Edgington's normal curve method, based on the contrast of the *p*-value average (Edgington 1972). Values range from 0 (adverse effect for the carbon emissions reduction) to 1 (beneficial effect for the carbon emissions reduction). One-tail *p*-value is a significance indicator by design; we report indicator "B" ("N") if the overall pooled one-tail *p*-value is significant at the 10% level.

Table 3 The Effects of Carbon Policies on Carbon Emissions: Comparison between Carbon Tax and ETS

Relationship (Random-effect model)	n1	n2	k	ρ	95%C.I.	*z*-value
carbon tax → carbon emission	41	861	7,312,819	-0.09	-0.099/-0.091	-19.229***
ETS→ carbon emission	48	1141	21,899,146	-0.025	-0.027/-0.024	-26.483***
Relationship (Fixed-effect model)						
carbon tax → carbon emission	41	861	7,312,819	-0.016	-0.017/0.015	-43.455***
ETS→ carbon emission	48	1141	21,899,146	-0.006	-0.006/-0.006	-28.1***

Notes. This table reports the meta-analytic results of sample size weighted mean of correlations (Borenstein et al. 2009, Vanneste et al. 2014) and compares the effects of carbon tax versus ETS on carbon emissions. n1 is the number of studies; n2 is the number of total effect sizes; k is total number of observations used in all studies; The ρ estimate is based on partial correlations, which are obtained from correlation coefficients or the *t*-values of the regression coefficients according to Peterson and Brown (2005) and Greene (2008). 95% C.I. is the lower and upper bounds of confidence internal around ρ; *z*-value is the *z* value when the test is full. *, **, *** indicate significance at the 5%, 1%, and 0.1% levels, respectively. Variables are defined in Appendix B.

Table 4 Meta-Analytic Test

Relationship	Heterogeneity			Publication Bias
	χ^2	I^2	Fail-safe n	*z*-value for observed studies
carbon tax → carbon emission	112842.706***	99.238	12915	-65.233***
ETS→ carbon emission	11647.179***	90.212	18440	-51.884***

Notes. This table reports the meta-analytic tests for homogeneity and publication bias. χ^2 is the chi-square test for homogeneity; I^2 is scale free index of heterogeneity. Fail-safe n refers to the number of unpublished studies reporting null results needed to reduce the cumulative effect across studies to the point that the 95% confidence interval includes zero. *, **, *** indicate significance at the 5%, 1%, and 0.1% levels, respectively. Variables are defined in Appendix B.

Table 5 Robustness check

Panel A Average effect size per study						
Relationship (Random-effect model)	n1	n2	k	ρ	95% C.I.	Z-value
carbon tax → carbon emission	41	41	107848	-0.117	-0.146/-0.088	-7.802***
ETS → carbon emission	48	48	546246	-0.044	-0.055/-0.033	-7.903***
Relationship (Fixed-effect model)						
carbon tax → carbon emission	41	41	107848	-0.033	-0.039/-0.027	-10.954***
ETS → carbon emission	48	48	546246	-0.019	-0.021/-0.016	-13.871***

Panel B Excluding unpublished papers						
Relationship (Random-effect model)	n1	n2	k	ρ	95% C.I.	Z-value
carbon tax → carbon emission	27	501	775089	-0.131	-0.162/-0.1	-8.174***
ETS → carbon emission	39	855	16981498	-0.039	-0.041/-0.036	-30.05***
Relationship (Fixed-effect model)						
carbon tax → carbon emission	27	501	775089	-0.042	-0.044/-0.04	-37.042***
ETS → carbon emission	39	855	16981498	-0.007	-0.007/-0.007	-30.05***

Panel C Excluding studies in which data units are firm, plant, etc.						
Relationship (Random-effect model)	n1	n2	k	ρ	95% C.I.	Z-value
carbon tax → carbon emission	37	602	686937	-0.13	-0.162/-0.097	-7.752***
ETS → carbon emission	36	605	947165	-0.085	-0.093/-0.077	-19.333***
Relationship (Fixed-effect model)						
carbon tax → carbon emission	37	602	686937	-0.048	-0.05/-0.045	-39.523***
ETS → carbon emission	36	605	947165	-0.042	-0.044/-0.04	-41.233***

Notes. This table shows the robustness check of the main meta-analytic results. n1is the number of studies; n2 is the number of total effect sizes; k is total number of observations used in all studies; 95% C.I. is the lower and upper bounds of confidence internal around ρ; *z*-value is the *z* value when the test is full. *, **, *** indicate significance at the 5%, 1%, and 0.1% levels, respectively. Variables are defined in Appendix B.

Table 6 Heterogeneity Analysis: Country Characteristics

Dependent variable:	Continuous Fisher's z-score											
Carbon policy:	Carbon tax			ETS			Carbon tax			ETS		
	(1)			(2)			(3)			(4)		
	Coeff.	t	Sig.	Coeff.	t	Sig.	Coeff.	t	Sig.	Coeff.	t	Sig.
Carbon policy environment												
Pollution level	0.024	1.037		0.011	1.659	*						
Financial development	-0.655	-0.747		-1.954	-5.831	***						
GDP growth	-0.082	-1.181		-0.100	-6.896	***						
Legal System	0.256	1.271		0.017	0.408							
Tax enforcement	0.817	1.249		-1.549	-5.078	***						
No. of Researcher	0.020	0.597		-0.010	-0.614							
Regions (Japan as reference)												
USA							-0.264	-3.877	***	-0.133	-6.268	***
Europe							-0.194	-5.583	***	0.009	0.356	
Canada							-0.160	-4.313	***			
Asia excluding Japan							-0.585	-4.174	***			
China										-0.062	-3.744	***
Publication controls												
Ln no. of observations	0.044	3.915	***	0.042	8.940	***	0.045	4.432	***	0.034	8.707	***
Research method	0.151	2.907	***	-0.000	-0.004		0.086	2.709	***	0.045	3.628	***
Published	-0.001	-0.023		0.517	7.084	***	-0.042	-0.807		0.067	3.408	***
Subsample	0.029	1.734	*	0.062	5.501	***	0.040	2.065	**	0.043	4.389	***
Publication year	-0.005	-0.532		0.007	1.286		-0.013	-1.735	*	0.009	2.231	**
No. of citations	0.000	0.572		-0.000	-1.533		0.000	2.104	**	0.000	0.816	
No. of effects	0.001	0.572		0.000	1.977	**	-0.000	-0.793		0.000	0.785	
Median year	0.012	0.726		-0.013	-2.784	***	0.008	1.849	*	-0.009	-2.488	**
Data type	-0.038	-1.192		1.107	19.681	***	-0.091	-1.697	*	1.078	21.159	***
Constant	-13.329	-0.359		10.722	0.815		10.433	0.705		-2.403	-0.245	
No. of studies	17			40			28			42		
No. of observations	559			1,074			650			1,115		
Adj. R^2	0.200			0.290			0.168			0.220		

Notes. This table reports the meta-analytic regressions to explain the heterogeneity of the effects of carbon policies on carbon emissions by country-level characteristics and region effects. The dependent variable is Fisher's z-score. The reported *t*-statistics are based on robust standard errors. Variables are defined in in Appendix B. The *, **, and *** indicate the coefficients that are significantly different from zero at the 10%, 5%, and 1% levels, respectively.

Table 7 Heterogeneity Analysis: Industry and Classification of Carbon Emissions

Dependent variable:	Continuous Fisher's *z*-score											
Carbon policy:	Carbon tax (1)			ETS (2)			Carbon tax (3)			ETS (4)		
	Coeff.	t	Sig.	Coeff.	t	Sig.	Coeff.	t	Sig.	Coeff.	t	Sig.
Industry												
CO2-intensive industry	-0.188	-2.460	**	-0.061	-1.975	**						
Carbon emission (Coal is reference)												
CO2							-0.098	-3.872	***	-0.052	-4.734	***
Electricity							-0.095	-3.812	***	-0.057	-5.448	***
Energy							-0.136	-6.571	***	-0.045	-3.000	***
Fossil fuel							-0.139	-5.654	***	-0.061	-4.758	***
Other							-0.098	-5.563	***	0.035	2.091	**
Publication controls												
Ln no. of observations	0.045	2.069	**	-0.001	-0.408		0.035	5.423	***	0.027	8.419	***
Research method	-0.150	-2.436	**	0.124	3.165	***	0.032	1.609		-0.011	-0.768	
Published	0.028	0.338		0.136	3.743	***	-0.026	-1.028		-0.060	-5.808	***
Subsample	-0.024	-0.889		0.017	1.970	**	0.019	1.391		0.032	3.521	***
Publication year	-0.009	-1.094		-0.046	-3.149	***	-0.006	-1.063		0.010	2.637	***
No. of citations	-0.002	-1.843	*	0.000	0.126		-0.000	-0.234		0.000	1.813	*
No. of effects	-0.002	-1.467		0.000	0.766		-0.000	-0.255		-0.000	-1.584	
Median year	-0.027	-1.884	*	0.037	3.157	***	0.000	0.064		0.003	0.976	
Data type	0.166	1.446		0.192	3.621	***	-0.016	-0.467		0.017	0.238	
Constant	72.379	1.844	*	18.062	0.742	**	11.482	1.018		-27.365	-2.375	**
No. of studies	10			11			39			46		
No. of observations	242			269			856			1,135		
Adj. R^2	0.171			0.648			0.114			0.230		

Notes. This table reports the meta-analytic regressions to explain the heterogeneity of the effects of carbon policies on carbon emissions by industry and classification of carbon emissions. The dependent variable is Fisher's *z*-score. The reported t-statistics are based on robust standard errors. Variables are defined in Appendix B. The *, **, and *** indicate the coefficients that are significantly different from zero at the 10%, 5%, and 1% levels, respectively.