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An Introduction to Carbon Pricing

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An Introduction to Carbon Pricing

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Abstract

This study provides an introduction to carbon pricing mechanisms through micro- and macro-based empirical analysis. The first part provides an overview of existing market-based regulations, comparing instruments in terms of emissions coverage, price structures, and revenue generation. The statistics show that the implementation of regulations follows a positive trend worldwide but remains far below the level required to initiate the transition to carbon neutrality. The heterogeneity of carbon prices and coverage underscores the need to increase the stringency of these policies. In the second part, we examine firm-level carbon pricing data from the Carbon Disclosure Project (CDP) database. Most companies have less than 10% or more than 90% of their Scope 1 emissions covered by regulation. Among respondents, 27% are subject to an external carbon price, 26% have an internal carbon price (ICP), and only 13% use both, suggesting that companies generally do not fully internalize carbon costs. Adjusting for survival and universe biases, we find that ICP adoption has been limited in recent years. Many companies committing to future adoption are not taking action, raising concerns about greenwashing. Finally, we conclude this study with an econometric application to test the relationships between internal and external carbon pricing. Using data from the MSCI World index in 2022, we estimate the main motivations for a firm to adopt an internal carbon price and the determinants of its price level. Firms in carbon-intensive sectors (e.g., utilities, energy, industrials) and those subject to external regulation are more likely to adopt an ICP.

Keywords: Climate change, carbon pricing, carbon tax, emissions trading scheme, shadow price.

JEL classification: G11, C01.

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1 Introduction

Tackling climate change will require innovative strategies to reduce greenhouse gas (GHG) emissions in the coming years. By assigning a cost to carbon emissions, carbon pricing has emerged as a key mechanism in efforts to achieve carbon neutrality. These mechanisms create economic incentives to reduce GHG emissions, thereby driving both behavioral change and technological innovation. However, these mechanisms are not cost neutral, but the longer their implementation is delayed, the more expensive they will become (Daniel *et al.*, 2019). Choosing low-impact policies will only increase these costs (Blanchard *et al.*, 2023).

The most common carbon pricing mechanisms include carbon taxes, cap-and-trade systems, and emissions trading systems (ETS). A carbon tax is a market-based instrument in which governments impose a fixed price on each ton of carbon dioxide emitted. The tax is designed to reflect the social cost of carbon, encouraging emitters to reduce their emissions to avoid higher costs. The simplicity and predictability of carbon taxes make them attractive, although setting the appropriate tax rate and coverage to balance economic and environmental goals remains a challenge (Semet, 2024). In contrast, cap-and-trade systems and ETS impose a cap on total emissions and distribute or auction a limited number of allowances that permit the holder to emit a specified amount of carbon. Companies can trade these allowances on the secondary market, creating a carbon price that reflects the dynamics of supply and demand. This mechanism is particularly effective in providing flexibility and economic efficiency, as companies with lower abatement costs can sell their excess allowances to those with higher costs, ensuring that the overall cap is met in a cost-effective manner. However, regulating emissions through a cap-and-trade system makes the price of carbon more volatile and uncertain than a carbon tax (Pizer, 1997).

A consistent observation emerges from the literature. The current use of carbon pricing mechanisms falls short of the thresholds needed to drive a true paradigm shift (Carhart *et al.*, 2022). Although countries with national or subnational carbon pricing policies account for over 70% of global GDP and about 60% of greenhouse gas emissions, only 23% of global emissions are effectively regulated (World Bank, 2023). Consequently, a key factor in the environmental transition is not the widespread adoption of carbon pricing mechanisms, but rather their stringency. Indeed, these instruments are insufficiently ambitious, especially in their ability to broaden the range of sectors covered and to raise the carbon price dramatically in the short term (Stiglitz *et al.*, 2017).

While public environmental policies have had a mixed track record, the emergence of internal carbon pricing (ICP) schemes has raised hopes for change in the private sector. This approach uses an internal, or shadow, carbon price to account for carbon costs and guide business decisions. It helps companies prepare for future regulations, manage the transition risk to a low-carbon economy, and drive investment in sustainable technologies (Bianchini and Gianfrate, 2018; Bento *et al.*, 2021). ICP is gaining attention among companies seeking to align their strategies with long-term environmental goals while responding to stakeholder pressure for greater sustainability (Harpankar, 2019).

This paper is organized as follows. Section Two provides an overview of existing carbon pricing mechanisms. This panorama sheds light on the stage of development of policies worldwide, in particular their stringency and limitations, such as sector coverage, carbon price structure, and revenue generation. Section Three shifts to a micro-level analysis using CDP database to explore how companies are incorporating transition risks into their strategies. After presenting statistics on external carbon pricing across sectors, markets, and firms, we analyze the internal adoption of carbon pricing among companies in the MSCI World index. We use regression models to estimate the factors driving ICP adoption and to identify the determinants of price levels. Finally, section four provides concluding remarks.

2 A panorama of carbon pricing mechanisms

To optimize the environmental transition, policies should be subjected to cost-benefit analysis (CBA). The environmental transition entails costs, *i.e.* the economic impact of implementing the policy. These costs are generally expressed as macroeconomic disruptions, such as the likelihood of economic slowdown or inflationary pressures, but can also be micro-oriented, such as competitive distortions and distributional impacts on household welfare. On the other hand, there are benefits associated with the environmental transition. Benefits are usually presented as a counterfactual, i.e. how much carbon has been saved by the policy compared to the business-as-usual (BAU) scenario. However, because the worst effects of climate change may be nonlinear over a long time horizon, calibration uncertainties of the damage function remain (Peck and Teisberg, 1993; Tol, 2003; Weitzman, 2010). As a result, costs may be relatively easy to estimate, while benefits are much more difficult to assess (Ackerman and Heinzerling, 2001).

CBA leads to a constrained optimization problem: maximizing emission reductions while minimizing economic costs. From a financial perspective, an investment should be approved if the discounted benefits exceed the current costs. Although this cost minimization rationale holds in a synthetic financial framework, such a perspective may be irrelevant in the public goods context (Tol, 2003). As Hardin (1968) puts it, we face a "*tragedy of the commons*". In other words, we are unable to sustain the use of a public resource. In fact, the climate is a public, limited, and indivisible good. Consequently, climate change is a global problem that requires a collective, or at least cooperative, response in order to be addressed effectively. Any progress in curbing emissions can be undermined by non-cooperative and harmful behavior such as free-riding (Barrett, 1994). For example, if one country decides to reduce its carbon footprint while all the others are not inclined to decarbonize their economies, the climate problem remains.

But the climate can no longer wait for this sterile position to be reversed. The first best solution, global and uniform carbon pricing, looks less and less like a realistic option (Roncalli and Semet, 2024). Nevertheless, some economies willing to make the transition have unveiled ambitious plans to comply with the Paris Agreement. These initiatives consist of market-based and non market-based solutions. Market-based instruments are economic mechanisms that regulate greenhouse gas emissions through price signaling theory. In contrast, non market-based mechanisms, or command-and-control regulations, impose standards (*e.g.*, technology or performance) on economic agents. The choice between the two types of regulation is based on the depth of information available to the regulator and the heterogeneity of the participants (Hepburn, 2006). In this section, we focus specifically on carbon pricing mechanisms that belong to the family of market-based solutions. We provide a panorama of existing carbon pricing policies and discuss their performance and limitations.

2.1 An overview of existing pricing mechanisms

2.1.1 Market-based solutions

In theory, the consumption or production of goods and services generates a negative externality that must be managed to maintain the same level of welfare. Economic theory suggests that market failure can be corrected by internalizing the external costs of CO_2e emissions (*e.g.*, sea level rise, crop failure, forest fires) into prices. A price signal is sent to the emitter to provide incentives to reduce emissions. This carbon pricing mechanism can take different forms and shapes. In this study, we are particularly interested in two main instruments, namely price-based and quantity-based instruments (Weitzman, 1974).

The carbon tax and the cap-and-trade system are the two emblematic pricing instruments. Other tailor-made mechanisms have also been developed, notably crediting mechanisms, subsidies, results-based climate finance (RBCF) or internal carbon pricing (World Bank, 2023).

A carbon tax imposes a price on the carbon content of fossil fuels, usually expressed as a monetary unit per ton of CO_2e. The carbon tax is intended to make carbon-intensive products relatively more expensive and less accessible in order to redirect demand. It is a price instrument, which means that the price is known, while the quantity (*i.e.* the level of greenhouse gas emissions) can vary (Weitzman, 1974; Hepburn, 2006). Thus, the implementation of a carbon tax suggests that the cost is bounded, while the environmental outcome is *a priori* unknown. Therefore, the environmental outcome depends on individual motivations in response to more constrained production or consumption. These motivations depend on the market structure, the elasticity of substitution, and the degree of regulatory support.

When policy addresses emissions through a quantity-based instrument, it takes the form of an emissions trading system (ETS). In the carbon market, participants trade emission allowances to meet their quotas. Constrained emitters can reduce their emissions internally or buy allowances from participants. Two types of ETS have been developed to date: cap-and-trade systems and baseline-and-credit systems. In a cap-and-trade system, an emissions cap (*i.e.* a limit on the absolute level of emissions) is set within the ETS. Allowances are then distributed to participants in the form of quotas, either for free or through auctions. Companies with a surplus of allowances (*i.e.* quotas for emissions above the actual level of emissions) trade their allowances with companies that need more. In the baseline-and-credit system, baseline emissions are set at the company level. Credits are distributed to companies that have reduced their emissions below their baseline. Companies with a surplus of credits can trade them with companies that have a shortage. When supply and demand are met in the ETS, a market price for GHG emissions is established.

2.1.2 Instrument differences and similarities

Despite a consensus among economists on the need to use such mechanisms to achieve environmental objectives, the choice of instrument remains controversial. In practice, the internalization of the induced costs of emissions can be done through a quantity-based instrument, a price-based instrument, or a combination of both. According to Stavins (2022), the two instruments may have similar characteristics in terms of abatement costs, economic and carbon leakage risks, and revenues. While the two instruments are also closely linked in terms of social costs and distributive impacts, their implementation in practice seems to diverge. For example, the price level, the relationship with other environmental policies, the practical global cooperation, the use of revenues, or the distortion of competitiveness may vary depending on the choice of instrument (Parry *et al.*, 2022).

First and foremost, the structure of the two market-based instruments differs by design. The price is endogenously determined in cap-and-trade systems, while it is exogenous for carbon taxes. In other words, a price-based instrument sets marginal costs but allows production levels to behave endogenously. In contrast, a quantity-based instrument sets the level of emissions but makes marginal costs uncertain (Pizer, 1997). Knowing *ex-ante* the level of emissions may be attractive to policymakers inclined to pursue the decarbonization path through carbon budget constraints. However, the carbon price is more volatile in this context, which could discourage the development of clean technologies. Nonetheless, by providing more certainty about emission levels, the ETS may be more acceptable to companies than a carbon tax (Parry *et al.*, 2022). In addition, cap-and-trade instruments are associated with higher transaction[1] and administrative costs than carbon taxes (Helm, 2005; Green, 2021). Second, policy homogenization[2] across jurisdictions is more feasible between cap-and-trade systems than carbon taxes (Mehling *et al.*, 2018). However, an ETS is less efficient than a carbon tax when it overlaps with complementary policies. This is mainly due to the distortion of abatement costs and allowance prices by other policies (Goulder and Stavins, 2011). In addition, cap-and-trade systems are more complex to design and may be more susceptible to corruption and market manipulation than carbon taxes (Stavins, 2022).

Comparing the potential performance of the two instruments highlights the advantages and disadvantages of each. Because one instrument can be designed to incorporate features of the other, economists have considered combining the two instruments within the same framework to form a hybrid system (Roberts and Spence, 1976; Weitzman, 1978; Pizer, 1997). For example, Roberts and Spence (1976) established a framework in which firms choose between buying permits on the market or directly from the government at a given price. The system becomes a pure carbon market when the level of emissions is fixed and as long as the cost of permits is below the given price. Conversely, the system is close to a carbon tax when the marginal cost is fixed and close to the price. In other words, adding a price floor and ceiling (*i.e.* a price collar) as a tax moderator[3] to an allowance auction system transforms the pure cap-and-trade system into a hybrid system that limits carbon price volatility (Pizer, 1997; Stavins, 2022). A carbon tax can also be extended with cap-and-trade features. Accordingly, the tax system can include tax rate adjustments (Metcalf, 2009) and direct revenues to mitigation activities, reducing the offset mechanism in the cap-and-trade system (Murray *et al.*, 2017).

2.1.3 Carbon pricing at a glance

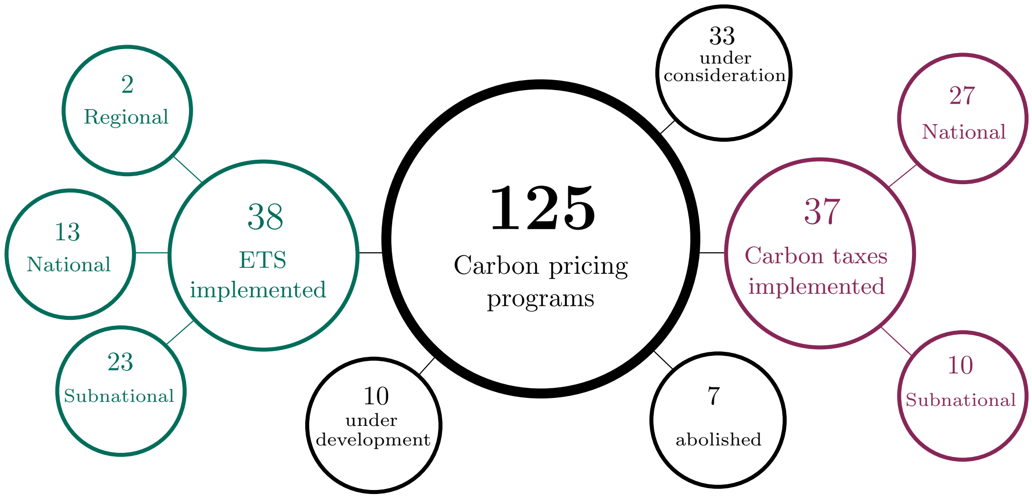
According to ICAP (2023), there are 36 ETS programs in 2023, distributed at the national, sub-national, and regional levels. The EU ETS covers 30 national jurisdictions (EU 27 plus Iceland, Liechtenstein, and Norway), the RGGI regulates nine American states, the Chinese pilots cover eight provinces, and the Japanese ETS regulates two provinces (Saitama and Tokyo). The EU ETS is the largest and most historic program, with phase one beginning in 2005. For carbon taxes, World Bank (2023) makes an inventory of 37 schemes, divided into twenty-seven national and ten sub-national programs. Finland was the first country to introduce a carbon tax of $1.4/tCO$_2$e in 1990 to reduce greenhouse gas emissions. Figure 1 shows the global network of carbon pricing mechanisms that we have collected from ICAP (2023), World Bank (2023) and CDP (2023). The individual data are reported in Tables 27 and 28 on pages 56 and 58. We obtain a total of 125 programs, 75 have been implemented (38 ETS and 37 CT), 10 are under development (9 ETS and 1 CT), 33 are under consideration (20 ETS and 13 CT), while 7 have been abolished (3 ETS and 4 CT). The program is under consideration once the government has announced its intention to implement a carbon pricing instrument. Australia and Vietnam are the next countries to announce the implementation of an ETS. Overall, the use of carbon pricing mechanisms is fairly balanced between carbon taxes and ETS. In the CDP database we have a flag for 34 ETS and 36 CT. Issuers may report figures for other carbon tax programs, but the data is not structured in the CDP database, making it difficult to analyze.

[1]For example, Coria and Jaraitė (2019) empirically showed that transaction costs (*e.g.*, monitoring, reporting, and verification) are significantly higher for an ETS than for a carbon tax.

[2]This refers to the linking of regional, national, and sub-national policies to create an environmental consortium.

[3]In this hybrid framework, the government buys back (or sells) permits when the permit price reaches the floor (or ceiling) price, which reduces (or increases) emissions (Hafstead *et al.*, 2017).

Figure 1: The global network of carbon pricing mechanisms



Source: Table 26 on page 56.

2.1.4 Internal carbon pricing

To monitor transition risk, companies have recently adopted internal carbon pricing (ICP) practices. ICP is a non-binding approach that companies use to manage and anticipate the carbon price risk associated with the likelihood of a carbon-constrained world. The initiative consists of internalizing the social cost of carbon. As a risk management tool, ICP assesses the compliance risk of a stringent carbon price, making the company more resilient to regulatory climate policies. It can also be integrated into the company's decarbonization strategy to identify carbon-intensive production and facilitate the reallocation of resources to low-carbon activities. According to CDP (2021), fewer than 900 companies disclosed their use of internal carbon pricing in 2020. However, the number of companies planning to do so in the coming years increased steadily, reaching 1 100 in 2020. The manufacturing sector is over-represented, accounting for nearly one-third of all ICP initiatives.

Three main methods have been considered for internally pricing the carbon. Shadow pricing involves projecting the carbon price and the resulting environmental costs associated with an investment. The goal is to consider the potential impact of a carbon price on a company's projects, such as capital expenditures (CAPEX), acquisitions, or R&D investments. As a result, environmental considerations are integrated into the decision-making process, potentially influencing the selection of projects based on their environmental efficiency. This approach is the most widely used and is generally adopted by companies in high-emitting sectors such as energy, chemicals, and manufacturing (I4CE, 2016). Another method is the internal fee approach, which imposes an internal charge on GHG emissions. It should be viewed as a carbon tax framework, as GHG emissions generated by operations are voluntarily charged, increasing the operational expenditure (OPEX) of the company. The proceeds can be used to finance transition funds aimed at decarbonizing the company's operations. In contrast to shadow pricing, the internal fee approach is generally adopted by companies in sectors with lower Scope 1 and 2 emissions. Finally, implicit carbon pricing is also categorized as ICP by CDP. It consists of retroactively calculating the company's abatement cost, *i.e.* the cost of reducing GHG emissions. This benchmark price is critical for setting pathways and targets to achieve net-zero goals. However, unlike the other two practices, it does not directly incentivize or engage in decarbonization efforts.

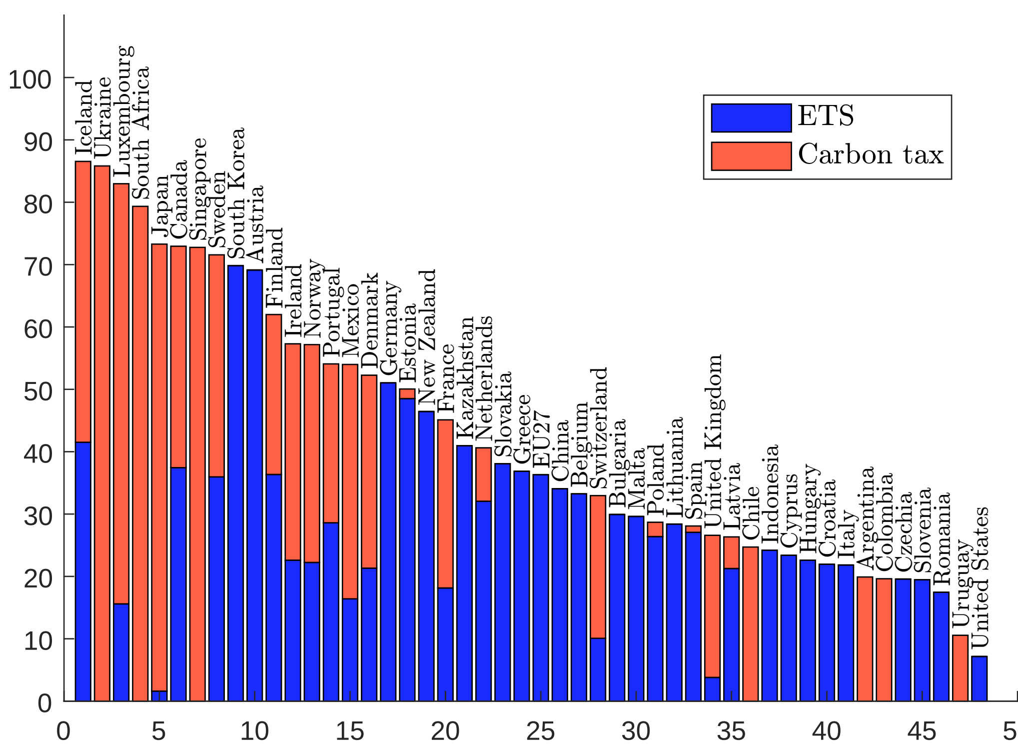
2.2 Designing a carbon pricing scheme

2.2.1 Emissions and sector coverage

Countries with implemented national or sub-national carbon pricing policies account for more than 70% of global GDP and about 60% of GHG emissions. For now, Australia, Brazil, India, Indonesia, and Turkey are the big absentees from this panorama. While the share of global emissions from countries covered by a pricing mechanism may seem large, the share actually covered by these mechanisms is quite different. World Bank (2023) estimates that only 23% of global emissions are subject to regulation. In 2023, 5.4% and 17.6% of global GHG emissions are under a carbon tax and a carbon market, respectively.

In Figure 2, we show the nationwide coverage of ETS and carbon taxes in 2022. The coverage of sub-national schemes is aggregated at the national level. Cross-coverage between individual national pricing mechanisms and the EU ETS can be disentangled using information from the EU Transaction Log database (EUTL, 2023). Any potential source of overlap between policies has been corrected to obtain an accurate estimate. In other words, we add the coverage resulting from the EU ETS to the individual pricing mechanism implemented while correcting for potential double counting of emissions under both programs. Finally, country emission estimates are obtained from EDGAR (2023).

Figure 2: Nationwide coverage in % of GHG emissions by carbon pricing mechanism in 2022



Source: World Bank (2023), EDGAR (2023), EUTL (2023) & Authors' calculations.

Some countries cover a large proportion of their emissions. This is particularly the case for Iceland, Ukraine, Luxembourg, South Africa, and Japan, which cover about 80% of nationwide emissions. Conversely, some countries are still in the early stages of implementing regulations, namely the United States and Uruguay, whose coverage is less than 10% of nationwide emissions. Regardless of the type of instrument, the median nationwide coverage is estimated to be 50% of GHG emissions in 2022. The choice of one instrument over the other appears to be relatively balanced across countries. At the country level, we count five countries that use only the price instrument to regulate emissions. In contrast, 20 countries have implemented only an ETS program, and 20 countries regulate GHG emissions with both an ETS and a carbon tax. As a result, ETSs are more widespread than carbon taxes. However, the average nationwide emissions coverage is slightly higher for carbon taxes (33%) than for ETSs (30%). The implementation of the pricing instrument at the national level seems to be broader on average than that of the ETS.

Differences in carbon tax design may explain the fragmented coverage of emissions across jurisdictions. In most cases, carbon taxes apply to emissions from fossil fuels (*e.g.*, gasoline, diesel, kerosene, gas oil, liquefied petroleum gas, fuel oil, natural gas, and solid fuels, including peat and coal). While all GHGs are generally included in the carbon tax framework, some policies are only linked to carbon dioxide. For example, the EU ETS only considers CO_2, nitrous oxide (N_2O), and perfluorocarbons (PFCs). The point in the supply chain at which the regulation requires payment of the tax is generally upstream, *i.e.* the sellers and importers of the covered fossil fuel bear the tax. However, it can also be at the source of the emissions, *i.e.* when the users release the emissions into the atmosphere.

In addition, the sectoral coverage of each instrument can vary widely from program to program. For example, emissions from agriculture or international aviation[4], which account for 12.7% and 2% of global emissions, respectively, are not covered by any instrument. In Tables 1 and 2, the sectoral coverage of existing carbon taxes and ETS varies across countries. This is mainly due to the non-overlapping policy combinations. In general, emissions covered by a carbon market are exempt from carbon taxes, and vice versa. For example, in Europe, with the exception of the United Kingdom, the Netherlands, and Estonia, which have an overlap rate of more than 80% (World Bank, 2023), countries implementing carbon taxes have small amounts of overlapping emissions with respect to the EU ETS. As a result, industrial production is the sector most likely to be fully or partially covered by carbon taxes, ahead of the energy sector. Nevertheless, the transport and buildings sectors are among the most fully covered, with about 60% of programs fully covering these emissions. In contrast, emissions from waste management and aviation are roughly covered by carbon taxes, as both are considered downstream emitters.

Some sectors are partially covered by the carbon tax, either for reasons of competitiveness or because of the wide dispersion of emissions. For example, in Sweden, exported fuels and fuels used in industrial processes (*i.e.* non-energy uses) are exempt. Note also that the number of sectors covered by the carbon tax is not directly related to the jurisdiction's share of total GHG emissions. For example, Norway has one of the most comprehensive carbon tax programs, covering almost all sectors, but only 63% of total emissions. Conversely, Singapore's carbon tax applies only to emissions from the energy, industry, and mining sectors, which account for nearly 80% of nationwide emissions. Along with South Africa and Liechtenstein, Singapore's carbon tax is one of the most comprehensive policies. Compared to ETS programs, sub-national carbon taxes are not as common. Some regions in Canada (*e.g.*, British Columbia, Northwest Territories, and Prince Edward Island) and Mexico (*e.g.*, Zacatecas) have considered the price mechanism to correct GHG emissions. Nevertheless, the range of emissions coverage is generally higher than national policies, reaching on average about 60% of the jurisdiction's total.

In the case of emissions trading schemes, regulation is particularly targeting emitters in the power generation, industrial production, and mining sectors (see Table 2). More

[4]Even with full sectoral coverage, regulations on aviation emissions apply only to domestic aviation.

Table 1: Sector and emission coverage of carbon tax programs

	Carbon tax program	Energy	Industry	Buildings	Mining	Transport	Aviation	Forestry	Waste	Agriculture	Coverage
National	Argentina	◐	●	○	◐	●	○	●	○	○	20%
	Canada federal fuel charge	◐	◐	●	◐	●	●	●	○	○	30%
	Chile	●	●	○	◐	○	○	○	○	○	29%
	Colombia	◐	●	●	◐	●	●	●	○	○	23%
	Denmark	●	◐	●	○	●	◐	●	○	○	40%
	Estonia	●	○	○	○	○	○	○	○	○	7%
	Finland	○	●	●	◐	●	○	●	○	○	36%
	France	○	◐	●	○	●	○	○	○	○	35%
	Iceland	●	●	●	○	●	○	●	○	○	55%
	Ireland	○	●	●	○	●	○	●	○	○	40%
	Japan	●	●	●	◐	●	○	○	○	○	75%
	Latvia	◐	◐	○	○	○	○	○	○	○	5%
	Liechtenstein	◐	●	●	○	●	○	○	○	○	81%
	Luxembourg	○	◐	●	○	●	○	○	○	○	65%
	Mexico	●	●	●	◐	◐	●	◐	○	○	44%
	Netherlands	●	●	○	●	○	○	○	◐	○	52%
	Norway	◐	●	●	◐	●	●	●	◐	○	63%
	Poland	◐	◐	○	●	●	○	●	○	○	4%
	Portugal	●	◐	●	○	●	◐	●	○	○	40%
	Singapore	●	●	○	●	○	○	○	○	○	80%
	South Africa	●	●	●	●	●	●	●	◐	○	80%
	Spain	○	◐	○	○	○	○	○	○	○	2%
	Sweden	◐	◐	●	○	●	○	●	○	○	40%
	Switzerland	◐	●	●	◐	○	○	○	○	○	33%
	United Kingdom	●	○	○	○	○	○	○	○	○	24%
	Ukraine	●	●	●	○	○	○	○	○	○	71%
	Uruguay	◐	◐	○	○	●	○	◐	○	○	11%
Regional	Canada										
	British Columbia	●	●	●	◐	●	●	●	○	○	70%
	Northwest Territories	●	●	●	◐	●	●	●	○	○	79%
	Prince Edward Island	●	●	○	◐	●	●	●	○	○	56%
	Mexico										
	Baja California	●	●	●	◐	●	●	○	○	○	
	Tamaulipas	●	●	●	●	○	○	○	○	○	
	Zacatecas	◐	○	○	○	○	○	○	○	○	50%

● Full coverage, ◐ Partial coverage, ○ No coverage

Source: World Bank (2023).

Table 2: Sector and emission coverage of ETS programs

	ETS program	Energy	Industry	Buildings	Mining	Transport	Aviation	Forestry	Waste	Agriculture	Coverage
National	Austria	◐	◐	●	○	●	○	●	○	○	40%
	Canada federal OBPS	◐	◐	○	○	○	○	○	○	○	1%
	China national	●	○	○	○	○	○	○	○	○	31%
	EU ETS	●	●	○	●	○	●	○	○	○	38%
	Germany	◐	◐	●	○	●	○	●	○	○	40%
	Indonesia	●	○	○	○	○	○	○	○	○	26%
	Kazakhstan	●	●	○	●	○	○	○	○	○	46%
	Mexico pilot	●	●	○	●	○	○	○	○	○	40%
	Montenegro	◐	○	○	○	○	○	○	○	○	
	New Zealand	●	●	●	●	●	●	●	●	◐	49%
	South Korea	●	●	●	●	○	◐	○	○	○	74%
	Switzerland	●	●	○	●	○	○	○	○	○	11%
	United Kingdom	●	●	○	●	○	●	○	○	○	28%
Regional	Canada										
	Alberta TIER	●	●	○	●	○	○	○	○	○	58%
	New Brunswick	●	●	○	●	◐	○	○	○	○	50%
	Newfoundland/Labrador	●	●	○	●	◐	○	○	○	○	43%
	Nova Scotia	●	●	●	○	●	○	○	○	○	87%
	Ontario EPS	●	●	○	●	○	○	○	○	○	25%
	Québec	●	●	●	●	●	○	●	○	○	77%
	Saskatchewan OBPS	●	●	○	●	○	○	○	○	○	13%
	China										
	Beijing pilot	●	●	●	●	●	○	○	○	○	24%
	Chongqing pilot	●	●	○	●	○	○	○	○	○	51%
	Fujian pilot	◐	●	○	●	○	○	○	○	○	51%
	Guangdong pilot	◐	●	●	●	○	●	○	○	○	40%
	Hubei pilot	●	●	●	●	○	○	○	○	○	27%
	Shanghai pilot	●	●	●	●	●	●	●	○	○	36%
	Shenzhen pilot	●	●	●	●	●	○	○	○	○	30%
	Tianjin pilot	◐	●	○	●	○	○	○	○	○	35%
	Japan										
	Saitama	◐	●	●	◐	○	○	○	○	○	17%
	Tokyo	◐	●	●	●	○	○	○	○	○	20%
	USA										
	California	●	●	●	●	●	○	●	○	○	74%
	Massachusetts	●	○	○	○	○	○	○	○	○	8%
	Oregon	◐	●	●	◐	●	○	●	○	○	43%
	RGGI	●	○	○	○	○	○	○	○	○	14%
	Washington	●	●	●	●	●	○	●	○	○	70%

● Full coverage, ◐ Partial coverage, ○ No coverage

Source: World Bank (2023), ICAP (2023) & Authors' calculations.

than 70% of ETS programs fully cover emissions from these sectors. Without exception, all ETS initiatives target energy-related emissions, either fully or partially. For the remaining sectors, 60% of ETS do not cover them. In contrast to the sectoral coverage of the carbon tax, ETS programs are less focused on transport and buildings. In terms of emissions coverage, South Korea's ETS is the most extensive program, covering over 70% of national emissions. It is the first nationwide and mandatory ETS in East Asia. New Zealand's ETS covers about half of its national GHG emissions, but has full coverage of almost all sectors. New Zealand is the only country that is required to cover GHG emissions from agricultural practices. However, these emissions will not be priced until 2026 (ICAP, 2023). Emissions from energy, particularly fuel combustion, account for more than 60% of emissions covered by the EU ETS.

Finally, it is worth noting at this stage of the analysis that estimates of instrument coverage are only a partial indication of the actual situation. While it may appear that a significant share of emissions is covered by pricing mechanisms, the actual coverage may in some cases be significantly lower. This discrepancy is due to a number of factors, such as accounting for preferential tax rates, eligibility for credits and offsets, and the amount of free allowances. As a result, the actual extent of regulated emissions may differ significantly from initial estimates.

2.2.2 Carbon prices

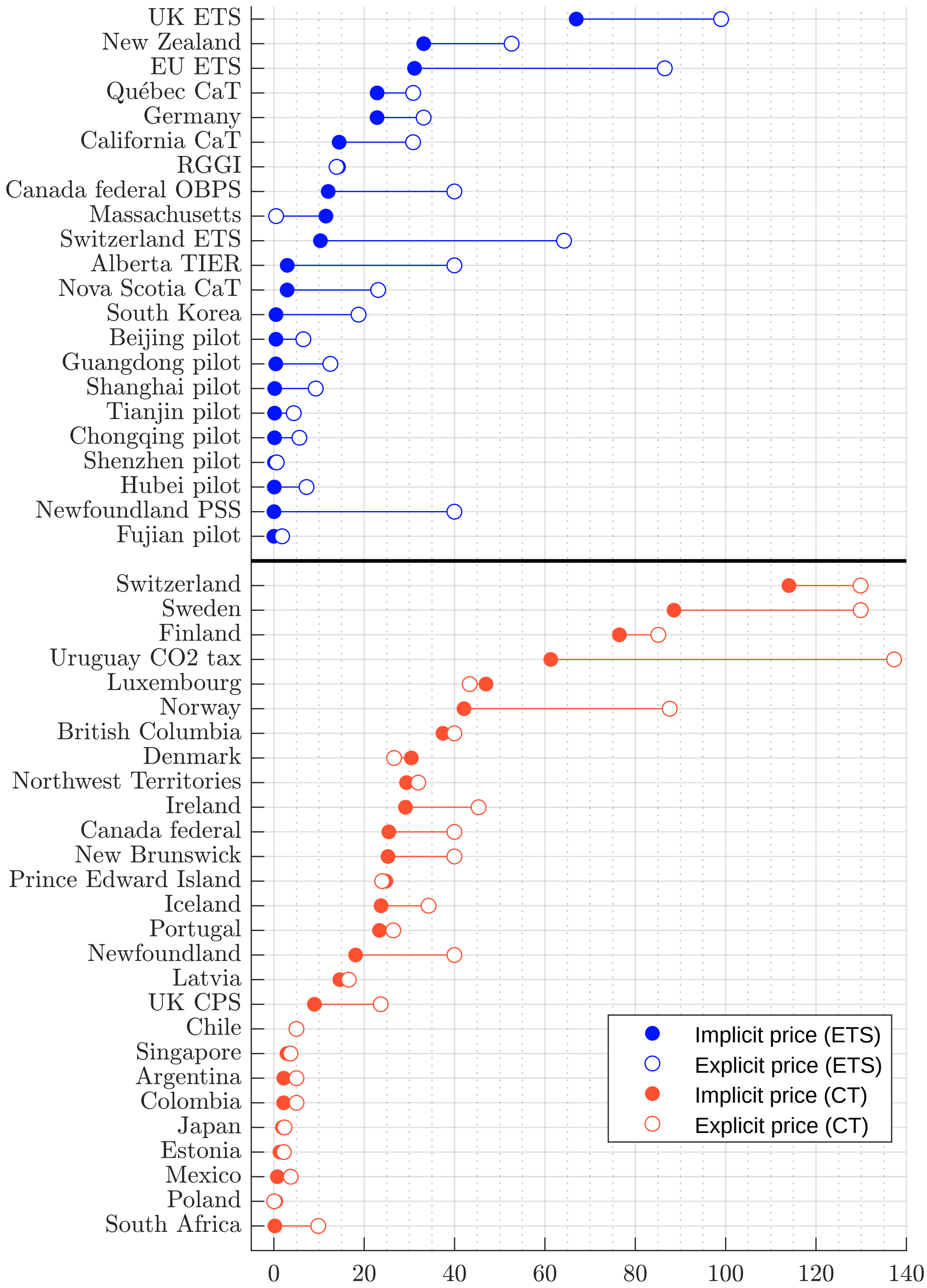
If the depth of emissions coverage is relevant for assessing the ambition of an instrument, the price at which emissions are paid remains the anchor point. The explicit carbon price is the price announced in official statements. For the ETS, the carbon price is the price at which allowances are auctioned on the primary market. In terms of GHG coverage, the heterogeneous design of carbon pricing mechanisms makes it difficult to compare instruments on the basis of the explicit price. Indeed, carbon prices may be applied to different gases, sectors, or stages in the supply chain. To overcome this heterogeneity problem, we can approximate the carbon price of each instrument by calculating its implicit carbon price and comparing it to the explicit carbon price. As in Desnos *et al.* (2023), the implicit carbon price $\mathcal{P}$ is the government revenue per unit of carbon dioxide equivalent covered:

$$\mathcal{P} = \frac{\mathcal{R}}{s^{\star}\,\boldsymbol{\mathcal{CE}}}$$

where $\mathcal{R}$ is the government revenue (in \$ mn), $s^{\star}$ is the covered fraction of emissions, and $\mathcal{CE}$ is the nationwide amount of GHG emissions (in MtCO_2e).

Figure 3 illustrates the state of the implicit and explicit carbon price (expressed in $\$/\text{tCO}_2\text{e}$) for each instrument type. First, with few exceptions, implicit prices are generally lower than explicit prices. For ETS programs, explicit carbon prices range from \$5 to \$95 per tonne of CO_2e, while implicit prices range from \$0 to \$50. For carbon tax programs, explicit carbon prices range from \$0 to \$134, while implicit prices range from \$0 to \$90. The spread between explicit and implicit estimates is due to the effective coverage of priced emissions by some form of tax exemption. The spread is even more pronounced for the most ambitious carbon prices, *i.e.* the higher the carbon price, the higher the exemption. In the case of the Swiss ETS, for example, the explicit carbon price is close to $\$95/\text{tCO}_2\text{e}$ but covers only 12% of national emissions, of which only 13% of allowances are auctioned (ICAP, 2023). Similarly, the Norwegian carbon tax reached $\$90/\text{tCO}_2\text{e}$ in 2023, but the effective tax rate was reduced to $\$7/\text{tCO}_2\text{e}$ for LPG and natural gas in the greenhouse industry. Only the New Zealand ETS and the French and British Columbian carbon taxes price carbon above its explicit price. This may be due to a scalable and non-unique carbon price. For

Figure 3: Implicit and explicit carbon price in 2022 (in $\$/tCO_2e$)



Source: World Bank (2023) & Authors' calculations.

example, France has several energy taxes with different coverage (*e.g.*, fossil fuels, natural gas, or coal) and rates (*e.g.*, from €1.2/MWh to €15/MWh).

Several programs have an implicit carbon price close to or below \$1. This is the case for most Chinese pilots, whose allocations are not auctioned and do not generate revenue, and the carbon taxes in South Africa and Ukraine. Recall that the nationwide emissions coverage of these two countries rises to nearly 80%. More broadly, there appears to be a global imbalance between emissions coverage and carbon prices. In other words, most ambitious regulations may lack the dimension of either coverage or price to be considered an effective game changer. Estimates suggest that more than 50% of emissions covered by instruments are implicitly priced below \$10 and almost 26% below \$1. More than 90% of covered emissions have a carbon price between 0 and \$25. Such a range of prices is far from what is recommended by the Stiglitz and Stern report (Stiglitz *et al.*, 2017). The authors stated that to achieve the Paris Agreement, the carbon price of existing instruments should be between \$40 and \$80 by 2020 and between \$50 and \$100 by 2030. By 2022, less than 1% of global emissions are implicitly priced above \$40/tCO_2e.

Comparing instruments by type, the carbon price is on average higher for carbon taxes than for emissions trading systems. The difference between explicit prices is relatively small, amounting to a gap of \$3. However, the difference between implicit prices is substantial, reaching about \$10.7. In fact, the revenue generated per tonne of CO_2e is much higher for carbon taxes than for ETS. This means that, on average, the quantity instrument generates less public revenue than an equivalent carbon tax (Carl and Fedor, 2016). This shortfall is mainly due to the distribution of free allowances, which by definition generate no revenue.

2.2.3 Carbon caps and allowance distribution

General principles In a cap-and-trade system, the responsible authority sets the carbon cap for the distribution of allowances to participants. The cap represents the total amount of greenhouse gas emissions allowed for covered activities. From year to year, the cap may decrease faster than verified emissions to encourage emission reductions. As the cap decreases over time, the quantity of allowances decreases and the price of allowances increases, creating incentives to decarbonize at an efficient cost. The carbon cap is typically expressed in terms of emission allowances, where one allowance gives the right to emit one tonne of CO_2. Emitters must provide as many allowances as they emit or face financial penalties. To meet this requirement, companies have several options. They can buy allowances on the carbon market, receive free allowances, use international credits, or reduce their emissions. In Table 3, we present some statistics on the absolute coverage, carbon caps, share of free allocation, and maximum offset limit of several ETS programs[5].

Although auctioning is becoming the standard method of allocating allowances, some specific sectors are still exempted from auctioning. The rationale is to protect these sectors or entities from competitive distortions and carbon leakage. Because the cost of compliance for high-emitting industries could be high enough to create an economic disadvantage and motivate relocation, these sectors are exempted from purchasing allowances. For example, in the Swiss ETS program, only 8% of the cap is sold by auction (see Table 3). Programs in the early stages of development are also considering free allocations to test the feasibility of the ETS. Such positive discrimination is not environmentally neutral. Although it does not harm the marginal benefit of GHG abatement *per se*, free allocation may break with decarbonization incentives. Entities benefiting from this privileged treatment are not encouraged to initiate carbon abatement and do not fall within the polluter-pays paradigm.

[5] The programs selected are those for which we have the most complete information from ICAP (2023).

Table 3: ETS program coverage, caps, free allocation, and maximum offset as of 2022

ETS program	Start year	Coverage (in $MtCO_2e$)	Cap (in $MtCO_2e$)	Free allocation	Maximum offset
EU ETS	2005	1 353.9	1 557.4	43%	0%
New Zealand	2008	38.4	51.2	46%	0%
Switzerland	2008	4.6	5.6	92%	0%
RGGI	2009	83.3	88.0	8%	3%
California CaT	2012	278.6	307.5	50%	4%
Kazakhstan	2013	135.8	140.3	100%	100%
Quebec CaT	2013	58.5	54.0	35%	8%
Korea	2015	506.9	589.3	97%	5%
Massachusetts	2018	4.6	8.0	0%	0%
Mexico pilot	2020	280.1	273.1	100%	10%
China national	2021	4 500.0	4 500.0	100%	5%
Germany	2021	304.8	291.1	0%	0%
United Kingdom	2021	113.4	151.4	46%	0%
Washington CCA	2023	56.7	67.4	53%	8%

Source: World Bank (2023), ICAP (2023) & Authors' calculations.

In addition, some programs allow emissions to be offset with international credits. Credits are financial instruments designed to eliminate or reduce greenhouse gas emissions through projects established by the Kyoto Protocol, namely the Clean Development Mechanism (CDM) and Joint Implementation (JI) (Roncalli, 2024a). However, the use of credits to meet requirements is becoming less accepted. For example, most historical ETS programs set the maximum proportion of a compliance entity's obligations that can be met by offsets at zero. This is the case for the EU ETS, the New Zealand ETS, and the Swiss ETS (Table 3). If the amount of allowances surrendered is less than the amount of emissions on time, the entity must pay a penalty for each tonne of emissions. For example, in the EU ETS program, the penalty is €100/tCO_2e, and the company's name is made public. In New Zealand, the missing allowance is three times the current market price.

Allocation of EU ETS allowances How allowances are distributed is the anchor point of any ETS program. To evaluate the allowance allocation process, we focus specifically on the EU ETS using data from the EUTL and aggregated by the European Environment Agency[6] (EEA). The EUTL does not directly provide auctioned allowances. Estimates are derived from public reports and trading platforms. We have aggregated estimates of total allocated allowances, free and auctioned allowances, verified emissions[7] and surrendered units, including certified emission reductions (CERs) and emission reduction units (ERUs). Table 4 shows the distribution of allocations by phase. Overallocation is the difference between total allowances and verified emissions. Figure 4 shows how greenhouse gas emissions have been managed in the EU ETS over the years.

During Phases I and II, the program was in a testing phase. While most allowances were freely distributed, the number of allowances allocated exceeded verified emissions. While economic turmoil dramatically reduced economic output and emissions, the overuse of international credits encouraged the creation of a large surplus of allowances. As a result, after eight years, the carbon market was in deficit. Companies have accumulated a surplus

[6]The EEA's EU ETS dataset is available at `https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1`.

[7]Verified emissions are GHG emissions from installations and aviation operators that have been verified by an independent audit.

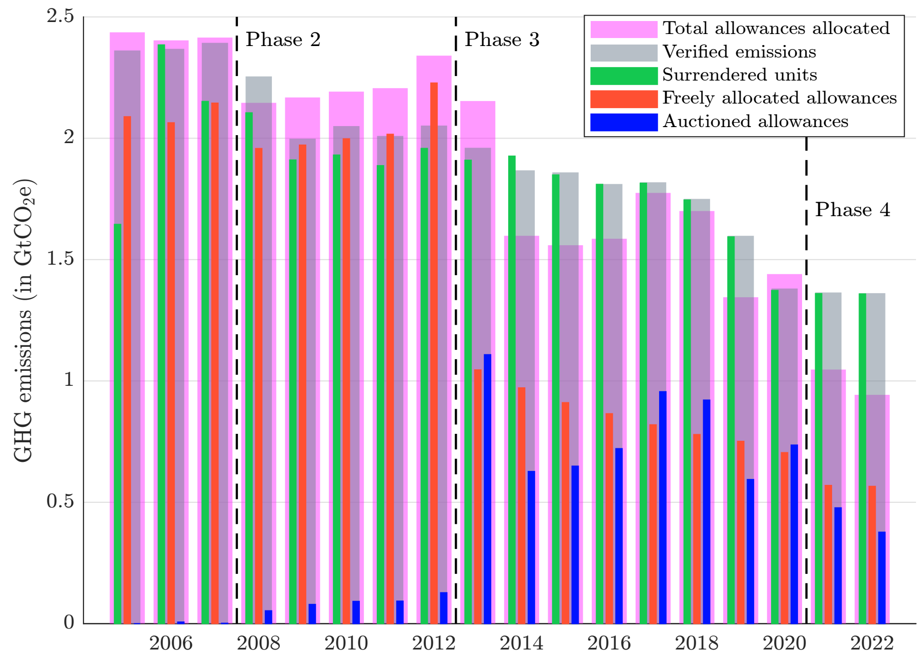
Table 4: Overallocation of allowances across EU ETS phases (in $GtCO_2e$)

Variables	Phase I	Phase II	Phase III	Phase IV
Total allowances	7.25	11.05	13.16	2.55
Verified emissions	7.12	10.37	14.05	2.73
Over-allocation	0.13	0.69	−0.89	−0.17
Cumulative surplus	0.13	0.82	−0.07	−0.25

Source: EUTL (2023) & Authors' calculations.

of allowances of about 0.82 $GtCO_2e$. At this stage, the free allocation mechanism was based on the *grandfathering* approach. Companies with relatively high historical GHG emissions received free allowances. As can be seen in Table 29 on page 60, the ratio of free allowances to verified emissions was significant in some sectors, particularly for carbon capture storage installations and ferrous materials.

Figure 4: Historical management of GHG emissions across EU ETS phases



Source: EUTL (2023) & Authors' calculations.

Several criticisms emerged as the grandfathering approach favored large emitters, breaking the incentive to reduce emissions. Electricity companies passed on the cost of allowances to their customers, even though they received free allowances. Since the beginning of Phase III, the distribution of free allowances follows a sector-based benchmarking approach, estimated at the product level and determined *ex-ante*. Free allowances are distributed according to the average emission level of the 10% most efficient installations in the sector. The most efficient installations should receive all or nearly all of the allowances necessary to meet their needs. Therefore, installations below the benchmarks should either reduce emissions or purchase allowances. However, the new distribution mechanism still lacked the flexibility to strengthen the regulatory framework[8].

[8] Allocations are estimated for eight years and cannot be easily updated.

The start of Phase III is also marked by the introduction of auctioning as the default allocation method. As reported in Table 29 on page 60, the latest estimates suggest that for all industrial installations (excluding aviation and fossil fuel combustion), the share of free allocation relative to verified emissions is 97% of verified emissions. Note that fossil fuel combustion installations are most affected by the gradual reduction in free allocation. This major change reduces the share to 71% for all stationary sources (excluding aviation). In addition, the cap has been abruptly reduced (see Figure 4), and some mechanisms have been introduced to restore the balance between supply and demand in the carbon market. The EU ETS Market Stability Reserve (MSR) was designed to freeze the auction volume in the reserve when the total number of allowances (TNAC) exceeds a certain threshold. In addition, the number of allowances in the reserve cannot exceed 400 million. As a result, the cumulative surplus became negative at the end of Phase III and has remained negative in early estimates for Phase IV (see Table 4).

2.2.4 Carbon pricing revenue

In addition to environmental benefits, carbon pricing instruments generate revenues. Revenue generation is an important, if not the most important, aspect of carbon pricing mechanisms. As noted in Carl and Fedor (2016), environmental benefits may take a long time to materialize and may be affected by regulations independent of carbon pricing mechanisms. As a result, the environmental aspect cannot be the sole justification for the adoption of a carbon pricing policy and may lose support[9]. As a result, carbon revenues and how they are managed could provide an anchor point for public support and evidence of policy effectiveness. In addition, some countries have firmly embraced carbon pricing instruments for this purpose. Ireland and Iceland, for example, considered carbon taxation as a means of raising revenue when they were under fiscal pressure. The Scandinavian countries were particularly interested in the possibility of a tax cut.

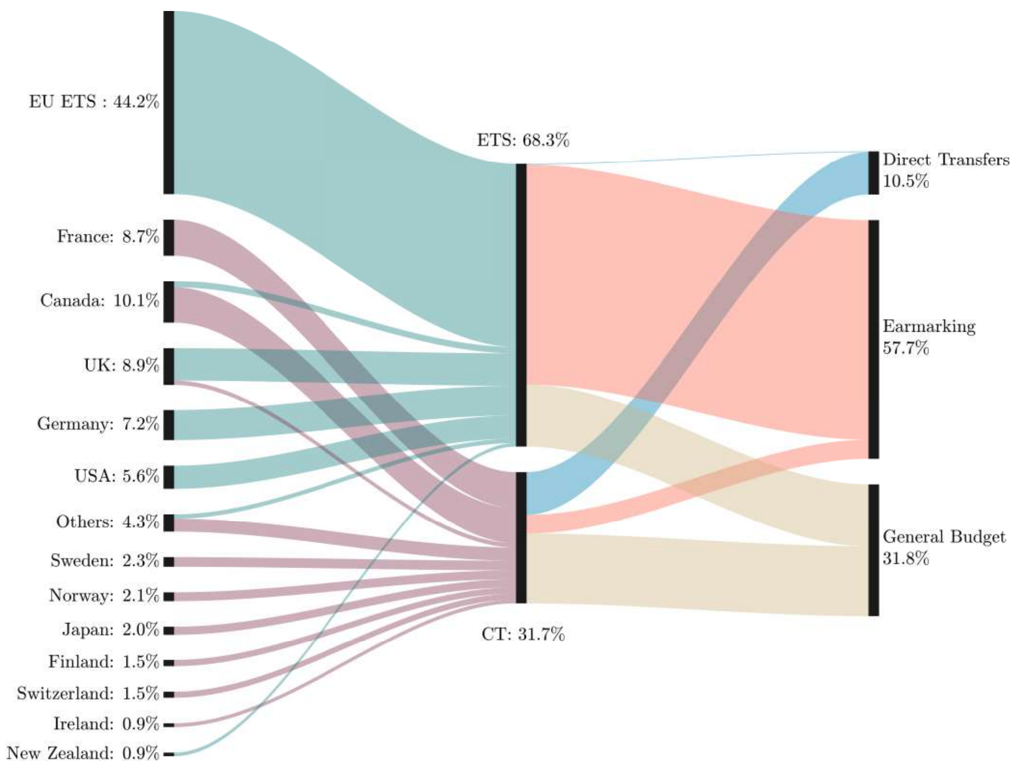
According to I4CE (2023), global revenues from carbon pricing mechanisms reached \$93 billion in 2022. In Figure 5, we provide estimates of the revenue generated for each program, as well as its ultimate use. Revenue is a function of price and emissions coverage (in the case of the ETS, emissions coverage subject to auctioning), with the EU ETS being the most prolific program (44% of total revenue). However, as emphasized earlier, the revenue generated per tCO_2e is substantially higher for carbon taxes than for emissions trading systems (Carl and Fedor, 2016). Overall, the size of the EU ETS explains the large dominance of ETS in global revenues. The gradual shift from free allocation to auctioning also contributes significantly to revenue expansion. According to the World Bank (2023), revenues from the EU ETS have grown by 500% over the past decade. Canada is the largest single contributor to revenue growth. Thanks to the relatively high emissions coverage of the carbon tax, Canada has generated up to \$9.4 billion in revenues. France follows closely with \$8 billion in carbon tax revenues. Thanks to its valuable carbon price, the UK ETS is the largest single contributor. With a contribution of 68%, ETS generate more than twice as much revenue as carbon taxes in 2022. On average, implemented ETS programs have raised \$4.9 billion, while the carbon tax has raised only \$1.5 billion.

When looking at the use of government revenues, there is a clear distinction between the two price mechanisms. We consider three categories: direct transfers, earmarks, and general budget. Direct transfers refer to all forms of budgetary transfers. Earmarking refers specifically to green projects such as green investments. The general budget represents the use of revenues for public expenditures such as tax cuts. Overall, carbon pricing revenues

[9] One can recall the main slogan of the Yellow Vets protest: "*End of the month before the end of the world*".

are disproportionately used for earmarking. This is mainly due to the large contribution of ETS to directing green investments. The earmarking share of revenues from ETS programs is about 77.7%, even if we exclude the EU ETS. The EU ETS Directive stipulates that at least 60% of revenues generated through auctioning should be used for climate and energy purposes. We understand the European Union's dual objective of constraining demand through the price mechanism while helping to transform the economy. Between 2013 and 2019, more than 78% of revenues have been earmarked for climate and energy investments. Consequently, the share of ETS revenues for direct transfers is almost non-existent. Carbon tax revenues are mostly earmarked for general budgets (53%) but also for direct transfers (32.5%).

Figure 5: Carbon pricing revenue generation and use (in % of total)



Source: I4CE (2023) & Authors' calculations.

2.3 The rationale for internal carbon pricing adoption

As carbon pricing policies tighten around the world, some companies have taken the lead in voluntarily internalizing carbon prices into their operations. In order to encourage and expand the adoption of such practices, it is important to understand the motivations behind them. Thus, several empirical studies focusing on ICP have attempted to identify the main reasons for the adoption of this practice in private organizations. A common argument is related to the risk management narrative. Companies view internal carbon pricing as a way to manage transition risk by incorporating the price of carbon as an additional cost into the business model. In other words, ICP implementation primarily helps to assess how sensitive and vulnerable the company's activities are to strict environmental regulations (Chang, 2017; Bianchini and Gianfrate, 2018; Bento *et al.*, 2021). Indeed, for the company's long-term strategic plan, the impact of the carbon price on the business model in certain sectors of activity is critical (Bento and Gianfrate, 2020) and may be the consequence of stakeholder pressure (Harpankar, 2019). In general, companies adopt ICP to anticipate the introduction of a constraining external carbon price, which would inevitably lead to a reduction in carbon intensity. Thus, it is not uncommon to find a strong correlation between ICP adoption and exposure to external carbon pricing (Harpankar, 2019; Bento and Gianfrate, 2020; Trinks *et al.*, 2022). For example, Trinks *et al.* (2022) found that firms exposed to external carbon pricing have a 10-13 percentage point higher predicted probability of adopting some form of ICP. Bento and Gianfrate (2020) suggested that the ICP is significantly higher for companies headquartered in countries with high GDP and an external carbon policy in place. It's easy to see why a company would be encouraged to use an ICP if it expects to be subject to an external carbon price in the near future, but why continue to support such a practice if such a regulation is already in place? Trinks *et al.* (2022) explained that the company may be anticipating rising external prices, may be using different ICP systems to meet personal targets, or may have simply implemented ICPs before the regulation was implemented.

While managing transition risk appears to be the most justifiable reason for adopting an ICP, according to World Bank (2023), one-third of companies that report using an ICP do not expect regulatory pressure in the coming years. For example, Ben-Amar *et al.* (2022) found that companies exposed to climate change are driving ICP adoption. Although these adopters may justify ICP programs for their own purposes, companies may also use them as a communication tool rather than to effectively initiate the decarbonization of their operations. In this way, companies can reassure concerned stakeholders while maintaining a healthy corporate image (Harpankar, 2019). Since then, the suspicion of voluntary and dubious claims made by carbon-intensive companies forces us to think about the growing risk of greenwashing. While this suspicion has already been noted in a number of articles (Doda *et al.*, 2016; Bento *et al.*, 2021; Trinks *et al.*, 2022), very few have actually investigated the link between ICP and carbon emission reduction. Therefore, one of the remaining questions is whether this additional constraint efficiently improves the environmental impact of the firm.

Recently, Gianfranco Gianfrate initiated an empirical analysis of the relationship between ICP adoption and the carbon footprint of companies[10]. Using a logit regression model with carbon intensity reduction as the dependent variable, he showed that ICP disclosure does not predict a change in decarbonization. However, the results also suggest that the issue is more strongly related to the stated commitment to use ICP in the future. In this case, ICP programs could initiate carbon reduction. Analyzing CDP's management practices, but independent of ICP adoption, Doda *et al.* (2016) didn't find compelling evidence of emissions reductions. They suggest three reasons for this: lack of data quality and standardization, potentially large time lags between the adoption of new practices and their environmental impact, and a lack of impact orientation in the purpose of the practices. On the other hand, several studies have found that increasing R&D investment and initiating technological innovation, especially those that implement internal fee collection, have a productive effect on carbon intensity reduction (Chang, 2017; Zhu *et al.*, 2022; Yanfei *et al.*, 2023). In addition, Byrd *et al.* (2020) found that emissions reductions are particularly faster for high-emitting and capital-intensive companies (*e.g.*, extractive industries, transportation, utilities, and manufacturing) than for similar companies that do not adopt ICP. Ma and Kuo (2021) went on to estimate the financial performance of ICP adopters. They concluded that such practices have a positive impact on a company's return on assets.

[10]Source: `https://climateimpact.edhec.edu/internal-carbon-pricing-impact-or-greenwashing`.

3 Empirical analysis

3.1 CDP questionnaire database

Each year since 2002, CDP sends out the CDP Questionnaire to company boards around the world. The questionnaire is a tool used to collect environmental data such as carbon emissions, energy use, water management, climate change strategies and carbon pricing mechanisms. In 2023, the questionnaire was sent to 14 170 companies. Approximately 40% (or 5 772 companies) complete the questionnaire and 60% (or 8 398 companies) do not respond. We retrieve the database as of October 2023 and analyze the different fields, in particular section C11, which is dedicated to carbon pricing. The data on these issues are organized into 9 categories listed below:

Category	Question text
C11.1	Are any of your operations or activities regulated by a carbon pricing system (*i.e.* ETS, Cap & Trade or Carbon Tax)?
C11.1a	Select the carbon pricing regulation(s) which impacts your operations.
C11.1b	Complete the following table for each of the emissions trading schemes you are regulated by.
C11.1c	Complete the following table for each of the tax systems you are regulated by.
C11.1d	What is your strategy for complying with the systems you are regulated by or anticipate being regulated by?
C11.2	Has your organization canceled any project-based carbon credits within the reporting year?
C11.2a	Provide details of the project-based carbon credits canceled by your organization in the reporting year.
C11.3	Does your organization use an internal price on carbon?
C11.3a	Provide details of how your organization uses an internal price on carbon.

Of the 5 772 companies that responded to the CDS questionnaire, 1 565 are regulated by an external carbon pricing scheme, while 1 504 use an internal carbon pricing scheme (Table 5). This represents 27% and 26% of respondents, respectively (Figure 6). Only 756 of the regulated companies (or 13% of respondents) reported that they are also implementing internal carbon pricing, meaning that half of the regulated companies are not cascading external carbon costs internally. 932 companies expect to be regulated in the next three years and 1 638 companies plan to implement an internal carbon pricing scheme in the next two years. Two main factors explain this asymmetry. The first is that 30% of regulated companies (454 out of 1 565) have the ambition to align internal interests with the external cost of carbon. The second is that internal carbon pricing is a voluntary decision. Non-regulated companies can therefore easily participate and implement internal carbon pricing schemes, especially companies that have announced net-zero targets. In Table 5, we also break down the 1 565 of regulated entities by carbon pricing scheme. 616 are subject to the carbon tax only, 702 are subject to the ETS only, and 244 are subject to both systems[11].

3.2 Carbon tax

In Table 6, we present statistics on the percentage of total Scope 1 emissions covered by carbon taxes[12]. While 860 companies reported being subject to carbon taxes, we only have

[11] Three companies do not report under which carbon pricing scheme they are regulated.

[12] These statistics are based on Category C11.1c, Question C3: *Complete the following table for each of the tax systems you are regulated by — % of total Scope 1 emissions covered by tax.*

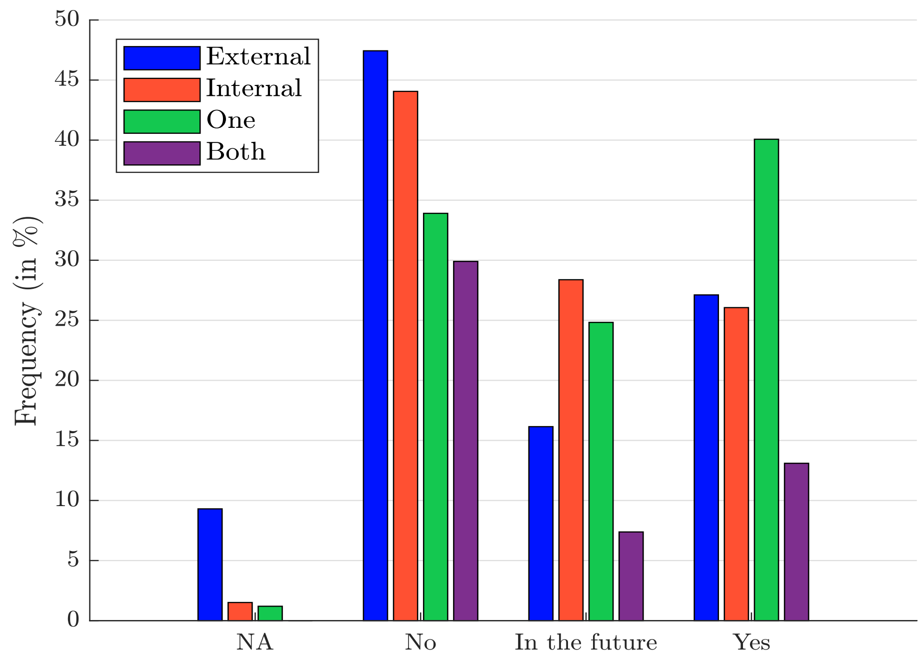
Table 5: Breakdown of companies with respect to external and internal carbon pricing mechanisms

		Internal carbon pricing				
		NA	No	In the future	Yes	Total
External carbon pricing	NA	69	219	108	141	537
	No	12	1 726	650	350	2 738
	In the future	3	246	426	257	932
	Yes	3	352	454	756	1 565
	CT	0	189	216	211	616
	ETS	2	123	188	389	702
	Both	0	39	50	155	244
	NA	1	1	0	1	3
	Total	87	2 543	1 638	1 504	5 772

In the case of an external carbon pricing system, the *No* and *In the future* tags correspond to the following responses: "*No, and we do not anticipate being regulated in the next three years*" and "*No, but we anticipate being regulated in the next three years*". In the case of an internal carbon pricing system, the responses are: "*No, and we do not currently anticipate doing so in the next two years*" and "*No, but we anticipate doing so in the next two years*". NA means we don't have the information.

Source: CDP Questionnaire database (2023) & Authors' calculations.

Figure 6: Frequency (in %) of external and internal carbon pricing mechanisms



Source: CDP Questionnaire database (2023) & Authors' calculations.

information on the percentage of total Scope 1 emissions for 770 companies. The CDP database includes 36 carbon taxes and a separate category for other carbon taxes. Of the 770 companies, 673 are subject to one carbon tax, 64 to two carbon taxes, 18 to three carbon taxes, and 15 to more than three carbon taxes. In total, we count 982 carbon tax observations, which means that, on average, a firm faces 1.28 carbon taxes.

Table 6: Carbon tax statistics for CDP reporting companies (number of companies and Scope 1 emissions covered by carbon tax in %)

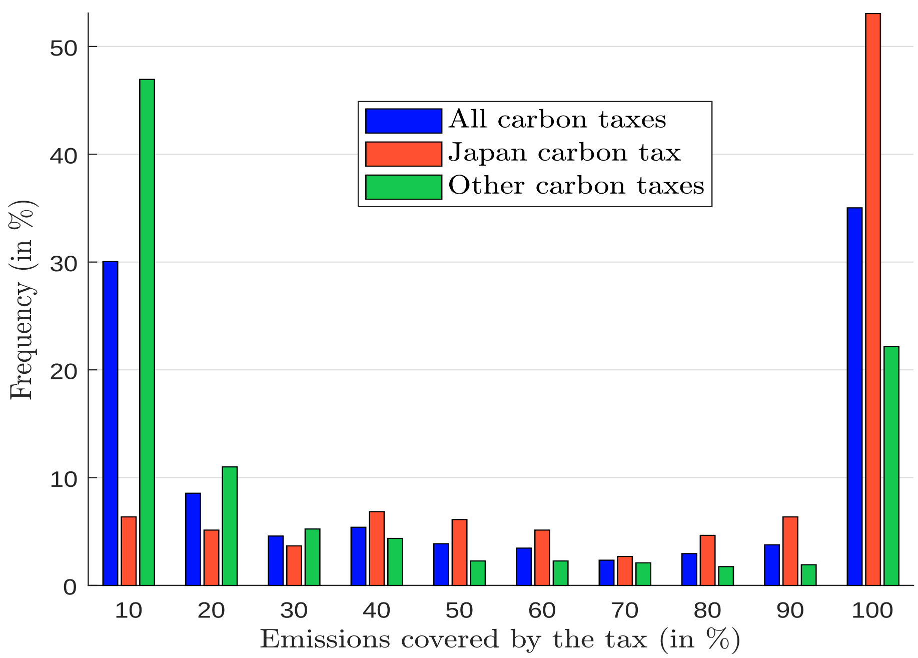
Name	#	Mean	Min	$Q_{25\%}$	$Q_{50\%}$	$Q_{75\%}$	Max
Japan carbon tax	409	73.2	0.02	44.6	94.0	100.0	100.0
Other carbon tax	84	33.2	0.02	1.9	16.5	57.0	100.0
South Africa carbon tax	63	44.1	0.02	6.6	31.2	91.3	100.0
Canada federal fuel charge	63	37.2	0.02	1.1	10.0	99.2	100.0
BC carbon tax	36	19.2	0.02	0.7	6.0	25.2	100.0
Ireland carbon tax	35	44.3	0.02	0.8	18.0	100.0	100.0
Switzerland carbon tax	34	31.1	0.10	1.0	14.6	43.0	100.0
France carbon tax	32	27.8	0.20	2.3	11.0	31.2	100.0
Mexico carbon tax	28	29.1	0.03	1.4	11.2	42.5	100.0
Sweden carbon tax	25	39.2	0.03	0.5	10.0	100.0	100.0
Singapore carbon tax	19	37.9	0.01	3.5	10.3	79.8	100.0
UK CPS	19	25.1	0.30	2.2	11.1	29.5	100.0
Norway carbon tax	17	44.4	0.02	2.9	24.0	93.0	100.0
Colombia carbon tax	15	18.0	0.11	0.6	1.9	19.6	100.0
Finland carbon tax	14	45.0	0.01	0.1	13.9	100.0	100.0
Denmark carbon tax	13	47.8	0.09	0.5	12.0	100.0	100.0
Chile carbon tax	13	47.3	0.05	12.2	40.4	85.8	100.0
Poland carbon tax	13	20.9	0.43	1.9	3.7	20.0	100.0
Netherlands carbon tax	13	20.0	0.03	0.6	5.0	13.2	100.0
Portugal carbon tax	9	46.6	0.04	0.5	28.0	100.0	100.0
Argentina carbon tax	5	25.0	0.04	0.3	4.7	40.0	100.0
Tamaulipas carbon tax	4	4.5	0.30	0.3	3.3	8.6	11.0
Spain carbon tax	4	1.6	0.02	0.0	1.6	3.3	3.4
Ukraine carbon tax	3	41.2	0.55	6.2	23.0	80.8	100.0
New Brunswick carbon tax	3	1.0	0.08	0.3	1.0	1.8	2.0
Newfoundland and Labrador	3	0.4	0.01	0.0	0.1	0.8	1.0
Slovenia carbon tax	3	0.2	0.10	0.1	0.2	0.2	0.2
Estonia carbon tax	1	100.0					
Luxembourg carbon tax	1	9.2					
Iceland carbon tax	1	0.8					
Total	982	50.2	0.01	5.0	43.0	100.0	100.0

Source: CDP Questionnaire database (2023) & Authors' calculations.

We found that the Japanese carbon tax is the most common, with 409 occurrences or 42% of the total observations. This is followed by the Canadian federal fuel charge and the South Africa carbon tax (63 observations or 6.4% of the total observations). There is a clear bias in the CDP dataset towards the Japanese carbon tax, as the total sample includes 1 244 Japanese companies, representing 22% of the total sample. Furthermore, only three foreign companies pay the Japanese carbon tax, meaning that 406 of the 409 occurrences correspond to Japanese companies. For each carbon tax, we calculated some statistics on the percentage of Scope 1 emissions covered by the tax. For example, in the case of the Japan carbon tax, the mean is 73.2%, the minimum is 0.02%, the first quartile $Q_{25\%}$ is 44.6%, the median $Q_{50\%}$ is 94.0%, while the third quartile $Q_{75\%}$ and the maximum are 100%. Looking at carbon taxes with more than 10 observations, Japan carbon tax has the highest average, followed by Denmark, Chile and Norway carbon taxes. In contrast, some regions have a low average, such as British Columbia, Colombia, the Netherlands, and Poland. Overall, the average percentage of Scope 1 emissions covered by the tax is 50.2%.

Figure 7 shows the distribution of Scope 1 emissions covered by the carbon tax. We notice that we get a U-shaped distribution, meaning that most companies are subject to a carbon tax that covers more than 90% or less than 10% of Scope 1 emissions. For example, considering all carbon taxes, out of 882 observations, there are 295 and 344 observations, respectively, that fall into the categories $\left(0, 10\%\right)$ and $\left(90\%, 100\%\right]$. This corresponds to 30% and 35% of the observations. Note, however, that there is a bias toward the Japan carbon tax. If we split the sample into two groups, one corresponding to the Japanese carbon tax and another corresponding to the other carbon taxes, the results are sensitively different. In fact, more than 50% of the observations fall into the last category $\left(90\%, 100\%\right]$ in Japan. In the other countries, the first category $\left(0, 10\%\right)$ dominates with 47% of the observations, while the last category $\left(90\%, 100\%\right]$ represents less than 25% of the observations.

Figure 7: Frequency (in %) of Scope 1 emissions covered by carbon taxes



Source: CDP Questionnaire database (2023) & Authors' calculations.

Table 7 shows the top 30 companies paying carbon taxes. We consider only the 36 identified carbon taxes and exclude the category "*other carbon taxes*" because there are some outliers in this last category[13]. As expected, Japanese companies are over-represented with 13 companies in the top 30.

[13] For example, Enel reports a payment of € 24.277 billion. They indicate that "*this figure refers to the Chilean market, which represents 9% of global Scope 1 emissions*". First, the Chilean carbon tax is already reported by Enel Chile SA. Second, it is obvious that the magnitude of the amount is wrong.

Table 7: Top 30 companies paying carbon taxes

Company	Country	Sector	Industry	Questionnaire sector	Total cost (in $ mn)
Enel Chile SA	Chile	Energy utility networks	Infrastructure	Electric utilities	1 939.2
Dangote Cement PLC	Nigeria	Cement & concrete	Materials	Cement	1 249.6
Suncor Energy Inc.	Canada	Oil & gas processing	Fossil fuels	Oil & gas	1 010.5
Bolloré SA	France	Media	Services	General	643.5
Equinor	Norway	Oil & gas processing	Fossil fuels	Oil & gas	483.6
Ecopetrol SA	Colombia	Oil & gas processing	Fossil fuels	Oil & gas	376.6
ENEOS Holdings	Japan	Oil & gas processing	Fossil fuels	Oil & gas	347.8
Idemitsu Kosan Co.	Japan	Oil & gas processing	Fossil fuels	Oil & gas	308.1
JERA Co.	Japan	Energy utility networks	Infrastructure	Electric utilities	262.8
ENERGA SA	Poland	Energy utility networks	Infrastructure	Electric utilities	223.7
Uniper SE	Germany	Energy utility networks	Infrastructure	Electric utilities	189.0
YPF SA	Argentina	Oil & gas processing	Fossil fuels	Oil & gas	168.9
Canadian National Railway Company	Canada	Rail transport	Transportation services	Transport services	94.5
Champion Iron Limited	Australia	Metallic mineral mining	Materials	Metals & mining	90.3
Electric Power Development Co	Japan	Thermal power generation	Power generation	Electric utilities	89.6
Canadian Pacific Railway	Canada	Rail transport	Transportation services	Transport services	75.3
Tokyo Gas Co.	Japan	Energy utility networks	Infrastructure	General	74.9
Tohoku Electric Power Co.	Japan	Thermal power generation	Power generation	Electric utilities	71.7
Teck Resources Limited	Canada	Metallic mineral mining	Materials	Metals & mining	65.2
Aker BP	Norway	Oil & gas extraction	Fossil fuels	Oil & gas	57.1
Kyushu Electric Power Co.	Japan	Thermal power generation	Power generation	Electric utilities	53.4
Kansai Electric Power Co.	Japan	Thermal power generation	Power generation	Electric utilities	50.4
Toho Gas Co.	Japan	Energy utility networks	Infrastructure	General	46.7
Sasol Limited	South Africa	Chemicals	Materials	Chemicals	45.9
Chugoku Electric Power Co.	Japan	Thermal power generation	Power generation	Electric utilities	41.9
Osaka Gas Co.	Japan	Energy utility networks	Infrastructure	General	41.2
SAS	Sweden	Air transport	Transportation services	Transport services	39.8
Hokuriku Electric Power Co.	Japan	Thermal power generation	Power generation	Electric utilities	39.7
Nippon Steel Co.	Japan	Metal smelting & refining	Materials	Steel	38.9
AES Corporation	United States	Energy utility networks	Infrastructure	Electric utilities	37.9

Source: CDP Questionnaire database (2023) & Authors' calculations.

Considering the 36 carbon taxes, we get a total of \$6.65 billion to be paid in 2022. This is a very low number, and there are three main explanations. First, many companies didn't respond (*e.g.*, Chevron, ExxonMobil, Glencore, Saudi Aramco, Stellantis, Tesla, Vitol). Second, some companies report zero carbon taxes, while we can assume they are subject to carbon taxes (*e.g.*, BP, Engie, Eni SpA, Iberdrola, Shell, TotalEnergies). Third, the CDP database is far from exhaustive, as only 675 companies and 271 non-Japanese companies have reported carbon taxes paid. The breakdown by industry is shown in Table 8. The fossil fuel industry pays the highest amount of carbon taxes, accounting for 38% of the total. This is followed by the materials and infrastructure industries, which account for 26% and 14% of total carbon taxes, respectively. Together, these three industries account for more than 75% of the total carbon taxes paid. If we filter out Japanese companies, the breakdown is very similar, except for the power generation industry[14].

Table 8: Amount of carbon tax paid by industry in 2022

Industry	With Japan			Without Japan		
	#	in \$ mn	in %	#	in \$ mn	in %
Fossil fuels	28	2 507.3	37.7	24	1 847.3	37.3
Materials	131	1 716.8	25.8	64	1 571.2	31.7
Infrastructure	64	948.1	14.3	25	513.1	10.4
Services	67	661.1	9.9	23	653.5	13.2
Power generation	14	438.7	6.6	2	41.9	0.8
Transportation services	32	249.9	3.8	13	246.1	5.0
Manufacturing	182	61.4	0.9	51	31.0	0.6
Food & agriculture	47	34.0	0.5	24	26.0	0.5
Retail	67	26.6	0.4	26	21.0	0.4
Biotech & health care	28	6.6	0.1	14	4.8	0.1
Hospitality	10	1.2	0.0	4	0.4	0.0
Apparel	5	0.7	0.0	1	0.0	0.0
Total	675	6 652.3	100.0	271	4 956.3	100.0

Source: CDP Questionnaire database (2023) & Authors' calculations.

Remark 1. *The results so far show that corporate data on carbon pricing is far from complete and of questionable quality. As a result, we need to be cautious in analyzing these data and not over-interpret them. This caveat applies to carbon taxes, but also to ETS and internal carbon pricing.*

3.3 ETS

In the case of ETS, the CDP database provides information on the following variables: (1) % of Scope 1 emissions covered by ETS; (2) % of Scope 2 emissions covered by ETS; (3) allowances allocated; (4) allowances purchased; (5) verified Scope 1 emissions in metric tons CO2e; (6) verified Scope 2 emissions in metric tons CO2e. We can then combine this information from category C11.1b with the Scope 1 and 2 emissions reported in categories C6.1 and C6.3.

[14] The fossil fuel industry includes companies involved in the extraction, production, and transformation of oil and gas. In parallel, the power generation sector is made up of companies that provide electricity (renewable, nuclear and thermal). The infrastructure industry is large, consisting of electricity networks, but also transportation, residential and non-residential construction).

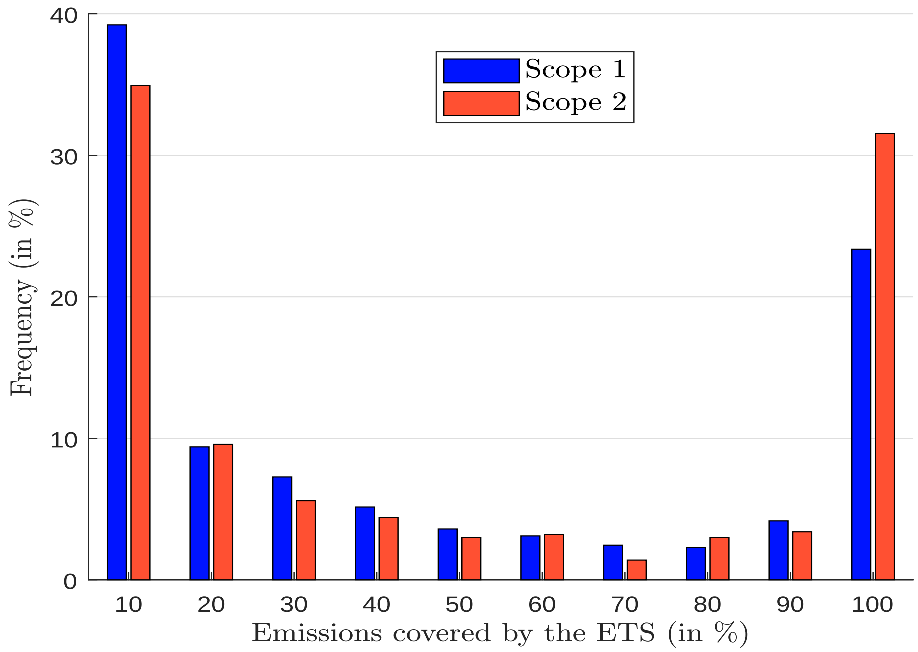
Table 9: ETS statistics for CDP reporting companies (number of companies and Scope 1 and 2 emissions covered by ETS in %)

Name	$\mathcal{SC}_1$			$\mathcal{SC}_2$			$\mathcal{SC}_{1-2}$
	#	Mean	$Q_{50\%}$	#	Mean	$Q_{50\%}$	#
EU ETS	403	45.8	35.0	41	42.2	35.0	39
UK ETS	122	25.8	7.3	13	38.4	18.0	9
Korea ETS	116	69.0	97.5	112	75.1	99.5	110
Tokyo CaT	89	22.3	7.0	97	32.9	14.0	84
Saitama ETS	51	21.3	6.5	51	25.7	7.7	48
California CaT	47	26.2	8.0	8	37.2	17.1	8
Alberta TIER	39	35.1	23.1	17	48.7	48.1	17
Shenzhen pilot ETS	33	27.0	2.6	34	52.5	41.5	32
Québec CaT	33	22.5	6.0	4	50.4	50.8	4
Shanghai pilot ETS	28	30.0	3.7	29	43.8	19.0	25
Ontario EPS	26	33.5	18.0	3	0.5	0.4	3
Other ETS	23	63.9	94.4	10	60.0	97.4	6
Canada Federal OBPS	23	47.4	33.9	3	67.3	100.0	3
Beijing pilot ETS	21	17.3	4.7	27	18.8	3.9	21
Switzerland ETS	21	10.6	2.0	3	37.4	12.0	1
Australia ETS	20	65.2	81.0				
China National ETS	16	51.0	41.5	12	47.7	33.6	12
Germany ETS	16	22.7	4.4	2	48.8		2
Saskatchewan OBPS	14	20.8	5.7	2	16.4		2
Mexico pilot ETS	13	55.0	43.5				
New Zealand ETS	11	77.3	95.0	1	100.0		1
RGGI	11	30.1	11.8	1	100.0		1
Kazakhstan ETS	8	83.0	99.8	3	100.0	100.0	3
Tianjin pilot ETS	7	22.4	11.0	8	30.3	17.0	6
Oregon ETS	5	9.2	10.0	3	15.7	10.0	3
Chongqing pilot ETS	4	36.6	23.1	4	30.4	10.6	4
Hubei pilot ETS	4	23.5	20.1	4	56.7	62.9	4
Washington CaT/CCA	4	19.7	18.5	1	26.0		1
Fujian pilot ETS	3	29.5	6.0	4	12.0	10.7	3
Nova Scotia CaT	3	13.4	1.0				
Guangdong pilot ETS	3	1.7	1.5	4	2.1	1.1	3
Newfoundland/Labrador PSS	2	50.0					
British Columbia ETS	2	20.0					
Massachusetts ETS	2	4.8					
New Brunswick ETS	1	99.0					
Total	1 224	39.2	21.6	501	45.7	29.7	455

Source: CDP Questionnaire database (2023) & Authors' calculations.

In Tables 32 and 33 on page 64, we report the number of CDP reporting companies by ETS and the scope of emissions covered by each ETS. We distinguish between Scope 1 and Scope 2 emissions. We find that 855 and 410 companies are regulated for their Scope 1 and Scope 2 emissions, respectively. In total, we count 1 224 and 501 ETS observations. On average, the ETS covers 39.2% and 45.7% of the Scope 1 and 2 emissions of these companies. These figures are higher than the median, which is 21.6% and 29.7%, respectively. This large difference is explained by the repartition, with a significant proportion of companies with 100% emissions coverage (Figure 8). Moreover, we observe that 21 companies are subject to Scope 2 emissions but not Scope 1 emissions (Table 9).

Figure 8: Frequency (in %) of Scope 1 and 2 emissions covered by ETS



Source: CDP Questionnaire database (2023) & Authors' calculations.

In terms of Scope 1 emissions, the EU ETS dominates the CDP database with 403 reporting companies and more than 30% of all ETS observations in the CDP database. This is followed by the UK ETS (122 companies), the Korea ETS (116 companies) and the Tokyo cap-and-trade (89 companies). For Scope 2 emissions, the Korea ETS represents 22% of the observations with 112 reporting entities. It is followed by the Tokyo CaT, the Saitama ETS and the EU ETS. For both Scope 1 and 2 emissions, the four largest ETS account for 60% of the observations. While Asian companies (China and Korea) represent 30% of reporting companies for Scope 1 emissions, they represent more than 75% of reporting companies for Scope 2 emissions. We observe some significant differences in the share of emissions covered by the ETS. For example, the average coverage rate for the Korea ETS is 69% and 75%. These figures become 46% and 42% for the EU ETS, 26% and 38% for the UK ETS, and 22% and 33% for the Tokyo CaT.

If we calculate the absolute amount of carbon emissions covered by the ETS, we find a total of 3 362 $MtCO_2e$. In this case we have the following breakdown[15]: 38% for the EU ETS, 11% for the Korea ETS, 5.6% for the UK ETS and 5.2% for the Québec CaT (Table 10). The distribution between Scope 1 and Scope 2 emissions is very heterogeneous. On average, 93% of covered emissions are Scope 1 and less than 7% are Scope 2. However, there are emissions trading schemes where Scope 2 covered emissions dominate Scope 1 covered emissions, notably in China. In contrast, Scope 2 covered emissions account for only 1% of the EU ETS[16]. Of the 3 362 $MtCO_2e$ of carbon emissions, 68.2% are verified. Again, we observe a high heterogeneity among ETS. About 100% of covered carbon emissions

[15]In Table 10, the category "*less than* 5 $MtCO_2e$" groups all ETS whose covered emissions are less than 5 $MtCO_2e$, *i.e.* Washington CaT/CCA, Saskatchewan OBPS, Switzerland ETS, Tianjin pilot ETS, Germany ETS, Oregon ETS, Massachusetts ETS, Fujian pilot ETS, British Columbia ETS, New Brunswick ETS, and Guangdong pilot ETS.

[16]The breakdown between Scope 1 and Scope 2 is shown in Table 34 on page 66.

Table 10: ETS statistics from CDP reporting companies (covered emissions, verified emissions and allowances)

Name	Carbon emissions			Carbon allowances			
	Covered (in $MtCO_2e$)	Verified (in $MtCO_2e$)	(in %)	Allocated (in $MtCO_2e$)	Purchased (in $MtCO_2e$)	Total (in $MtCO_2e$)	(in %)
EU ETS	1 271.2	989.1	77.8	423.0	472.9	895.9	70.5
Korea ETS	360.8	344.3	95.4	349.1	14.3	363.5	100.7
Other ETS	253.5	264.6	104.4	195.1	3.3	198.3	78.2
UK ETS	187.1	84.5	45.1	19.5	27.4	46.9	25.0
Québec CaT	174.3	6.0	3.4	7.3	0.2	7.5	4.3
Mexico pilot ETS	147.9	37.4	25.3	30.5	5.2	35.7	24.1
Alberta TIER	138.5	98.4	71.0	101.3	11.4	112.7	81.3
Kazakhstan ETS	136.7	25.2	18.5	25.5	0.2	25.8	18.8
Australia ETS	122.5	232.3	189.7	227.5	0.2	227.7	185.9
RGGI	90.8	46.9	51.6	9.6	71.5	81.1	89.2
California CaT	85.1	42.6	50.1	53.6	20.7	74.3	87.3
China national ETS	73.6	32.6	44.3	31.5	0.0	31.6	42.8
Ontario EPS	62.9	8.8	14.0	7.5	0.3	7.8	12.5
Shanghai pilot ETS	39.7	4.1	10.4	5.0	0.1	5.2	13.0
Newfoundland/Labrador PSS	33.5	0.0	0.1	0.0	0.0	0.0	0.0
New Zealand ETS	30.5	3.9	12.7	0.7	1.0	1.8	5.8
Canada federal OBPS	30.5	3.8	12.6	6.2	1.7	7.9	25.8
Hubei pilot ETS	23.4	0.6	2.6	13.9	0.2	14.1	60.1
Tokyo CaT	21.4	4.3	20.0	9.3	1.1	10.3	48.4
Saitama ETS	15.1	1.5	9.9	4.8	0.0	4.8	31.7
Shenzhen pilot ETS	12.3	6.8	55.7	6.3	0.5	6.8	55.5
Beijing pilot ETS	11.0	4.4	39.7	2.9	0.3	3.1	28.2
Nova Scotia CaT	5.9	5.9	99.3	0.1	0.0	0.1	1.1
Chongqing pilot ETS	5.0	0.1	2.8	0.2	0.0	0.2	4.7
Less than 5 $MtCO_2e$	28.6	44.1	154.1	11.4	5.3	16.7	58.4
Total	3 362.0	2 292.3	68.2	1 541.8	637.6	2 179.5	64.8

Source: CDP Questionnaire database (2023) & Authors' calculations.

are verified in Korea and Australia, 78% and 45% in the European Union and the United Kingdom, and less than 20% in Canada and Kazakhstan. As explained above the allowances allocated and purchased do not match the covered carbon emissions due to overlapping periods. Another factor is the data quality of the reporting companies. On average, the ratio of allowances allocated and purchased to covered carbon emissions is about 65%. For some ETS, the share of purchased allowances is high (*e.g.*, EU, UK, RGGI, California).

Table 11 shows the breakdown by industry. We retrieve the totals calculated in Table 10. The covered emissions are 3 362 $MtCO_2e$ for Scope 1 and 2 emissions, while the verified carbon emissions are 2 292 $MtCO_2e$. Again, there is a gap between allowances and covered emissions, as the sum of allocated and purchased allowances does not equal the covered emissions. Materials is the most representative industry and has the largest covered emissions (45% of total covered emissions). It is also the most representative in terms of CDP reporting companies (215 companies followed by 212 manufacturing companies). The other major industries are fossil fuels, power generation and infrastructure. They represent only 7%, 4% and 8% of companies, but 19%, 15% and 12% of covered emissions. On page 67 we show the differences between the EU ETS and the non-EU ETS. The breakdown by industry is relatively similar, with one major exception. Fossil fuel companies are more prevalent in the non-EU ETS than in the EU ETS (23% of total covered emissions vs. 12%). There are other significant differences, but they are small. This is the case for transport services, which are three times more representative in the EU ETS but account for only 3% of covered emissions.

Table 11: ETS statistics by industry in 2022 (covered emissions, verified emissions and allowances in $MtCO_2e$)

Industry	#	Covered			Verified	Carbon allowances	
		$\mathcal{SC}_{1-2}$	$\mathcal{SC}_1$	$\mathcal{SC}_2$	$\mathcal{SC}_{1-2}$	Alloc.	Bought
Materials	215	1 520.8	1 441.6	79.2	555.9	529.4	35.5
Fossil fuels	59	637.4	617.9	19.4	538.3	397.0	77.3
Power generation	37	488.4	478.1	10.3	581.1	398.3	187.2
Infrastructure	73	401.2	398.8	2.4	310.0	74.1	297.4
Manufacturing	212	119.8	43.3	76.5	66.8	63.8	9.1
Transportation services	47	71.2	70.5	0.7	168.5	20.9	20.7
Food & agriculture	77	50.1	44.2	6.0	19.4	8.2	6.7
Services	83	38.9	19.3	19.7	28.0	28.6	0.5
Retail	28	29.9	24.5	5.5	21.3	18.8	2.2
Biotech & health care	38	3.0	2.7	0.3	2.3	1.4	1.0
Apparel	4	1.0	0.4	0.6	0.6	0.7	0.0
Hospitality	3	0.2	0.0	0.2	0.1	0.6	0.0
Total	876	3 362.0	3 141.3	220.7	2 292.3	1 541.8	637.6

Source: CDP Questionnaire database (2023) & Authors' calculations.

Remark 2. *The previous analysis should be used with caution because the reported data is very noisy. For example, if we look at ArcelorMittal, they report* 113.435 $MtCO_2e$ *for Scope 1 emissions. They are subject to four ETS: EU ETS, Kazakhstan ETS, Mexico pilot ETS, and Québec CaT. The proportion of Scope 1 emissions covered by these ETS is* 100%, 77%, 99% *and* 100%, *respectively. This means that the Scope 1 emissions covered by an ETS are* $376\% \times 113.435 = 426.515$ $MtCO_2e$. *For Scope 2 emissions, we find* 6.157 $MtCO_2e$ (100% *of Scope 2 emissions due to the Québec CaT). The total is* 432.672 $MtCO_2e$. *This example illustrates double counting issues.*

Table 12: Top 40 companies subject to ETS in terms of covered emissions (statistics in $MtCO_2e$)

Name	Carbon emissions		Carbon allowances		
	Covered	Verified	Allocated	Purchased	Total
ArcelorMittal	432.7	74.4	68.2	0.0	68.2
Rio Tinto	164.5	11.8	4.5	0.1	4.6
China Shenhua Energy	146.8	237.0	189.7	0.0	189.7
Suncor Energy	135.4	33.3	29.8	2.3	32.1
TAQA	115.4	2.0	0.2	1.8	2.0
SABIC	98.8	2.2	2.5	0.2	2.7
CLP Holdings	88.3	214.2	214.2	0.0	214.2
RWE AG	83.0	83.0	0.7	81.3	82.0
PGE	70.4	42.1	0.6	42.1	42.7
POSCO	70.2	70.2	77.2	0.0	77.2
Heidelberg Materials	65.4	22.0	21.2	0.0	21.2
En+ Group	52.0	1.3	0.7	0.6	1.3
Alcoa Corp.	49.8	0.0	11.0	0.1	11.1
ENEL SpA	35.4	35.4	0.0	35.4	35.4
Korea South-East Power	35.4	35.4	38.8	3.5	42.2
Samruk-Energy JSC	33.0	0.2	0.2	0.0	0.2
Korea Midland Power	31.6	31.9	28.1	3.8	31.8
Korea Western Power	30.2	30.2	27.2	2.9	30.2
Korea East-West Power	29.2	29.2	25.1	2.3	27.4
Phillips 66	28.8	0.0	0.0	0.0	0.0
Hyundai Steel	28.5	28.5	29.3	0.8	30.0
United Co RUSAL	28.3	1.3	0.7	0.6	1.3
US Steel Corp.	25.9	7.3	6.3	1.0	7.3
Uniper SE	25.5	26.0	0.1	20.3	20.4
Huaxin Cement	25.5	0.0	13.8	0.0	13.8
Taiheiyo Cement Corp.	24.5	3.5	3.4	0.1	3.5
O-I Glass	24.3	2.7	2.6	0.7	3.3
TotalEnergies	22.7	37.2	22.7	7.0	29.7
Canadian Natural Resources	22.0	22.0	18.5	2.2	20.7
Engie	21.8	30.6	21.3	0.6	21.9
Indian Oil Corp.	20.9	0.0	0.0	0.0	0.0
Holcim	20.7	22.0	21.2	0.1	21.3
CEMEX	20.7	20.7	21.4	0.1	21.5
ORLEN	19.5	28.1	10.1	16.2	26.3
Gerdau	19.3	0.2	0.2	0.0	0.2
Dominion Energy	18.5	33.3	9.2	17.9	27.1
EDF	18.3	17.9	0.5	16.1	16.6
Thyssenkrupp AG	18.2	17.8	16.1	1.6	17.8
CEZ	17.6	17.6	0.3	17.3	17.6
LG	17.4	14.2	15.6	0.0	15.6
Tata Steel	17.3	11.9	16.3	1.0	17.4
Anheuser Busch InBev	17.1	0.3	0.2	0.1	0.3
Eni SpA	16.7	16.7	5.0	11.7	16.7
EnBW AG	16.6	17.1	0.1	17.0	17.1
Shell PLC	16.3	16.4	12.4	4.3	16.7
KazMunayGas National Company	16.1	7.5	7.6	0.5	8.1
Samsung Electronics	15.0	14.9	14.6	0.3	14.9
Public Power Corp.	14.7	14.9	0.0	15.9	16.0
CRH	14.7	14.7	14.7	0.0	14.7
Iberdrola	13.6	3.7	0.1	3.1	3.2

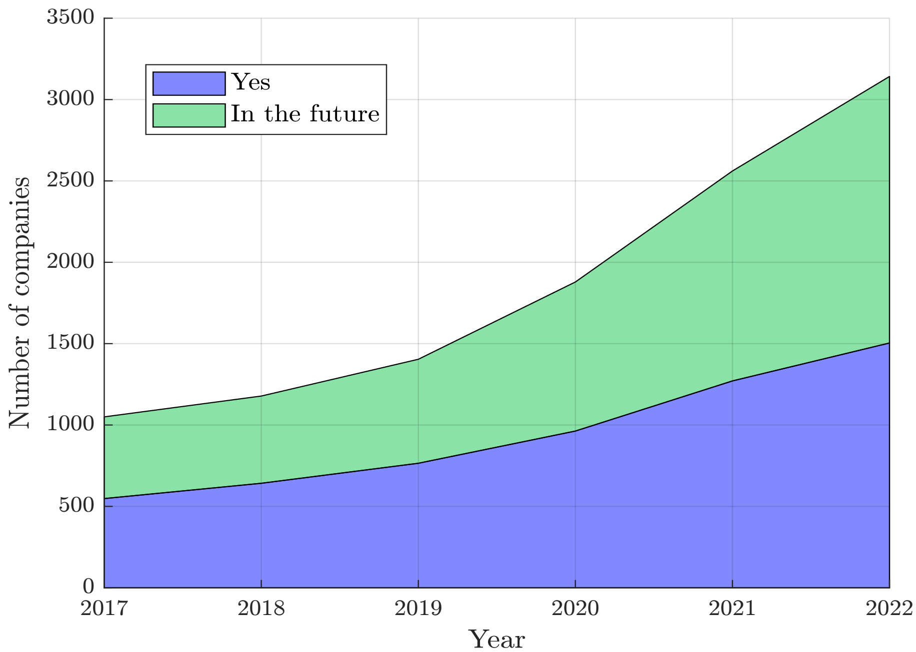
Source: CDP Questionnaire database (2023) & Authors' calculations.

3.4 Internal carbon pricing

3.4.1 Growth of internal carbon pricing

Many people believe that internal carbon pricing is increasingly being adopted by companies around the world. For example, it was the first key finding of the CDP report dedicated to internal carbon pricing (CDP, 2021). In Figure 9 we show the number of companies that are implementing internal carbon pricing or plan to implement internal carbon pricing in the next two years. At first glance, this figure seems to confirm the impressive growth of ICP adoption around the world[17]. In 2022, there were 1 504 companies using ICP, compared to only 548 companies in 2017. This represents an annual growth of 22.4%.

Figure 9: Number of CDP reporting companies using internal carbon pricing



Source: CDP Questionnaire database (2018-2023) & Authors' calculations.

Looking more closely at the numbers, it is not clear that the adoption of internal carbon pricing is widespread or has increased significantly. In Table 13 we report the statistics by year[18]. As with external carbon pricing, we have four categories: NA, No, In the future and Yes. We find that 80% of the growth of companies adopting ICP is due to growth

[17]This figure can be compared to the graph on page 6 of the CDP report. However, the numbers are different because they do not use the same perimeter. In our case, we only have access to the public database corresponding to the CDP climate change questionnaire (CDP core and sector questions only).

[18]We have to do some re-treatment to get homogeneous data for the six CDP questionnaires. First, the 2018 questionnaire (for the 2017 reporting year) does not distinguish between companies that respond to the questionnaire and companies that do not respond. All companies are grouped together on one sheet. However, the *Request Response Status* field provides the following information (1) completed, (2) declined to respond, (3) incomplete and (4) no response. We decide to group companies whose field's item is (1) or (3) into the *Responders* cluster and the others into the *Non responders* cluster. Since 2019, CDP has adopted this binary classification. In the 2020 questionnaire (for the 2019 reporting year), the *Responders* category also includes some subsidiaries (109 companies), whose reporting is exactly the same as that of the parent company. For example, the questionnaire filled by Christian Dior is the questionnaire filled by LVMH. We decided to exclude these 109 companies.

Table 13: Breakdown of companies on internal carbon pricing

Year	NA	No	In the future	Yes	Responders	Non responders	Total
2017	247	1 201	502	548	2 498	3 580	6 078
2018	143	1 195	536	642	2 516	3 355	5 871
2019	169	1 254	639	765	2 827	3 417	6 244
2020	203	1 282	916	963	3 364	3 779	7 143
2021	473	1 986	1 290	1 271	5 020	4 805	9 825
2022	87	2 543	1 638	1 504	5 772	8 398	14 170

The *No* and *In the future* tags correspond to the following responses: "*No, and we do not currently anticipate doing so in the next two years*" and "*No, but we anticipate doing so in the next two years*". NA means we don't have the information.

Source: CDP Questionnaire database (2018-2023) & Authors' calculations.

of companies reporting to CDP (annual growth of 22.4% vs 18.2%). If we calculate the adoption rate with respect to all respondents, we do not observe a continuous increase from 2017 to 2022 (Table 14). In 2017, 21.9% of companies used internal carbon pricing. In 2022, this figure rises to 26.1%, but peaks in 2020 at 28.6%. We conclude that progress toward internal carbon pricing is not as impressive when corrected for universe and survival bias.

Table 14: Company breakdown in %

Year	NA	No	In the future	Yes
2017	9.89%	48.08%	20.10%	21.94%
2018	5.68%	47.50%	21.30%	25.52%
2019	5.98%	44.36%	22.60%	27.06%
2020	6.03%	38.11%	27.23%	28.63%
2021	9.42%	39.56%	25.70%	25.32%
2022	1.51%	44.06%	28.38%	26.06%

Source: CDP Questionnaire database (2018-2023) & Authors' calculations.

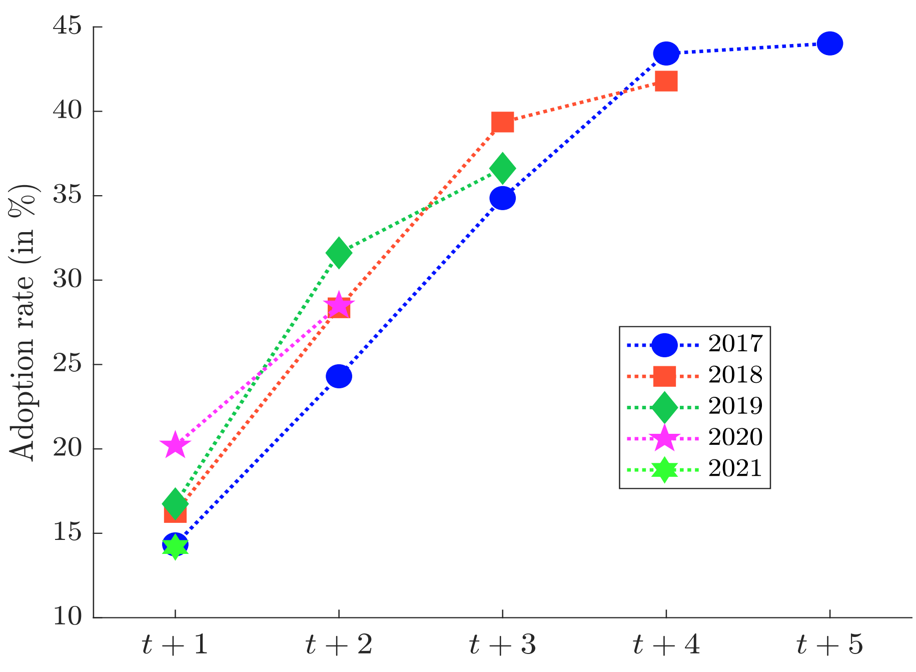
We also need to be careful about companies' promises to implement internal carbon pricing in the future. If this were really the case, we should see a more rapid increase in the number of *Yes* responses. For example, in 2017, 502 companies responded that they expected to implement internal carbon pricing in the next two years. This means that by 2019, the number of companies that have implemented internal carbon pricing should be at least 1 050, *i.e.* the 502 and 548 companies that answered *In the future* and *Yes* in 2017. However, there are only 765 companies that answered *Yes* in 2019. The reason is that many companies that committed to implementing ICP have not done so. We consider the companies at time t that answer *No, but we anticipate doing so in the next two years*. In Table 15, we analyze what they have answered at time $t + k$. We can get several cases: the company filled out the CDP questionnaire but didn't answer (NA), the company answered *No, and we do not currently anticipate doing so in the next two years* (No), the company still answered *No, but we anticipate doing so in the next two years* (In the future), the company answered *Yes* or the company does not fill out the CDP questionnaire (Non responder). For example, out of the 502 companies that answered *No, but we anticipate doing so in the next two years* in 2017, 221 have effectively implemented internal carbon pricing in 2022, while 50 companies have withdrawn. In Figure 10, we report the adoption rate, which is the number of companies answering *Yes* at time $t + k$ relative to the number of companies that answer *In the future* at time t. In the first year, the adoption rate is between 15% and 20%, while five years later it is between 40% and 50%. This is not too bad, but it also means that some companies have a greenwashing communication on this issue.

Table 15: What happens to companies that answer: *No, but we anticipate doing so in the next two years*

t	$t+k$	NA	No	In the future	Yes	Non responders	Total
2017	2018	0	41	361	72	28	502
	2019	1	49	287	122	43	502
	2020	1	43	234	175	49	502
	2021	2	44	191	218	47	502
	2022	1	50	168	221	62	502
2018	2019	1	34	391	87	23	536
	2020	1	38	312	152	33	536
	2021	2	46	237	211	40	536
	2022	1	54	208	224	49	536
2019	2020	0	25	492	107	15	639
	2021	2	45	359	202	31	639
	2022	1	60	301	234	43	639
2020	2021	2	61	629	185	39	916
	2022	2	78	521	261	54	916
2021	2022	2	79	956	183	70	1 290

Source: CDP Questionnaire database (2018-2023) & Authors' calculations.

Figure 10: Adoption rate of CDP reporting companies that answer: *No, but we anticipate doing so in the next two years*



Source: CDP Questionnaire database (2018-2023) & Authors' calculations.

Remark 3. *The previous analysis can be extended to companies that have already implemented internal carbon pricing. In Table 16, we report the future ICP status for companies that respond: Yes. For example, of the 548 companies that implemented ICP in 2017, only 409 companies continue to use ICP in 2022, while 30 companies have stopped using ICP and do not plan to use it in the next two years. It's interesting to note that some companies are backtracking, and this is not a marginal phenomenon, as it affects between 5% and 15% of companies.*

Table 16: What happens to companies that answer: *Yes*

t	$t+k$	NA	No	In the future	Yes	Non responders	Total
2017	2018	1	5	15	502	25	548
	2019	0	12	21	468	47	548
	2020	2	13	34	453	46	548
	2021	5	18	37	438	50	548
	2022	6	30	49	409	54	548
2018	2019	0	10	11	595	26	642
	2020	2	12	31	565	32	642
	2021	4	20	39	540	39	642
	2022	6	33	53	500	50	642
2019	2020	2	7	22	711	23	765
	2021	4	14	33	681	33	765
	2022	6	30	54	624	51	765
2020	2021	4	18	32	889	20	963
	2022	6	37	61	814	45	963
2021	2022	3	29	54	1 141	44	1 271

Source: CDP Questionnaire database (2018-2023) & Authors' calculations.

3.4.2 Behavior by industry and geography

Table 17: ICP statistics by industry in 2022 (number of companies & implementation rate)

Industry	NA	No	In the future	Yes	Yes (in %)	Total
Services	32	827	430	340	20.9	1 629
Manufacturing	23	646	434	301	21.4	1 404
Materials	8	170	180	290	44.8	648
Infrastructure	5	169	145	138	30.2	457
Retail	3	251	128	73	16.0	455
Food & agriculture	1	112	100	77	26.6	290
Biotech & health care	4	131	55	49	20.5	239
Transportation services	3	80	63	69	32.1	215
Fossil fuels	3	35	32	78	52.7	148
Power generation	0	30	18	67	58.3	115
Hospitality	2	53	33	7	7.4	95
Apparel	3	37	20	15	20.0	75
International bodies	0	2	0	0	0.0	2
Total	87	2 543	1 638	1 504	26.1	5 772

Source: CDP Questionnaire database (2023) & Authors' calculations.

In Table 17 we calculate the number of companies by industry and the breakdown according to the four possible answers: *NA*, *No*, *In the Future*, and *Yes*. We also show the percentage of companies that have implemented internal carbon pricing in 2022. For example, there are 1 629 companies in the services sector in the CDP database. 340 of these companies use ICP, which corresponds to an implementation rate of 20.9%. As expected, the implementation rate is high in power generation (58.3%), fossil fuels (52.7%) and materials (44.8%), and low in retail (16.0%), biotech & health care (20.5%) and services (20.9%).

Table 18: ICP statistics by country in 2022 (number of companies & implementation rate)

Country	NA	No	In the future	Yes	Yes (in %)	Total
Japan	10	560	392	282	22.7	1 244
US	42	696	180	158	14.7	1 076
UK	1	162	149	93	23.0	405
China	6	102	127	15	6.0	250
Korea	4	75	28	102	48.8	209
Germany	4	78	48	64	33.0	194
France	1	65	59	67	34.9	192
India	8	49	70	54	29.8	181
Brazil	0	44	58	61	37.4	163
Canada	2	79	36	43	26.9	160
Taiwan	0	32	55	73	45.6	160
Turkey	1	19	35	57	50.9	112
Italy	0	48	16	37	36.6	101
Sweden	2	42	32	21	21.6	97
Switzerland	1	30	27	36	38.3	94
Spain	0	21	27	36	42.9	84
South Africa	1	28	17	25	35.2	71
Ireland	0	31	23	15	21.7	69
Australia	1	26	20	20	29.9	67
Netherlands	0	24	20	23	34.3	67
Norway	0	21	16	21	36.2	58
Finland	0	23	9	19	37.3	51
Mexico	0	23	14	12	24.5	49
Belgium	1	24	10	13	27.1	48
Hong Kong	0	24	17	6	12.8	47
Other	2	217	153	151	28.9	523
Total	87	2 543	1 638	1 504	26.1	5 772

Source: CDP Questionnaire database (2023) & Authors' calculations.

We do the same exercise by looking at the breakdown by country (Table 18). Among the 25 most represented countries, Turkey has the highest implementation rate (50.9%), followed by Korea (8.8%), Taiwan (45.6%) and Spain (42.9%). These different results raise questions about the determinants of internal carbon pricing (Bento and Gianfrate, 2020), and we may wonder whether internal carbon pricing is related to external carbon pricing (Bento *et al.*, 2021). At first glance, we might assume that there is a positive relationship (because of the sectoral results). However, the rankings of Turkey and Taiwan are curious and may contradict this link. Similarly, the low scores for Sweden and Canada are troubling, as these two countries are known to be at the forefront of carbon taxes and ETS. This issue is discussed later.

3.4.3 Carbon prices

The CDP questionnaire collects a lot of interesting information about how companies are using the internal carbon price. Before 2022, companies are asked to provide the current price for each ICP scheme. Since 2022, they are asked to provide the minimum and maximum price for each ICP scheme over the year. In addition to these quantitative figures, companies provide qualitative information about the type of ICP, how the price is determined, etc. The list of information is shown below:

Category	Question text
C11.3a	Provide details of how your organization uses an internal price on carbon
C1	Type of internal carbon price
C2	How the price is determined
C3	Objective(s) for implementing this internal carbon price
C4	Scope(s) covered
C5	Pricing approach used: spatial variance
C6	Pricing approach used: temporal variance
C7	Indicate how you expect the price to change over time
C8	Actual price(s) used: minimum
C9	Actual price(s) used: maximum
C10	Business decision-making processes this internal carbon price is applied to
C11	Mandatory enforcement of this internal carbon price within these business decision-making processes
C12	Explain how this internal carbon price has contributed to the implementation of your organization's climate commitments and/or climate transition plan

In Table 19, we report the statistics for questions with checkbox answers. There are three main types of internal carbon prices:

- Implicit price is the cost a company actually incurs when it implements projects to reduce emissions. It's calculated based on past emission reduction projects;
- Internal fee is an internal charge paid by different departments of the company;
- Shadow price is an estimate of the cost of carbon abatement and reflects the potential cost of carbon emissions if future regulations or carbon markets make companies pay for their pollution.

The shadow price accounts for 68% of internal carbon prices and dominates the implicit price and internal fee categories (13% each). Companies can give different answers for setting the internal carbon price and the implementation target, so the frequencies do not add up to 100%.

Alignment with an ETS or carbon tax system is the main factor determining the level of the internal carbon price (35% and 26% respectively). Two other factors also have a response rate of more than 20%: the cost of meeting emission reduction targets and the cost of voluntary carbon offsets. These are all objective factors[19], while subjective factors such as the social cost of carbon are less represented. Regarding the objective of implementing internal carbon pricing, the main motivation is to transition to a low-carbon economy by promoting

[19] We can also include the category of peer benchmarking.

Table 19: How do CDP reporting companies use the internal carbon price?

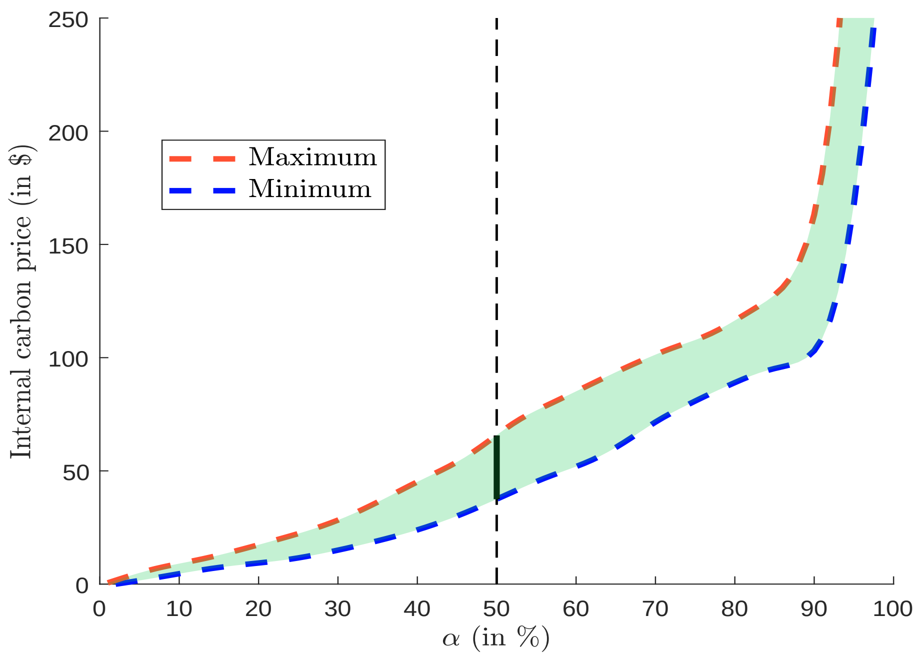
Question	#	%
What is the type of internal carbon price?		
Implicit price	211	13.3
Internal fee	214	13.5
Shadow price	1 078	67.9
Other	84	5.3
How is the internal carbon price determined?		
Alignment with the price of a carbon tax	409	26.0
Alignment with the price of allowances under an ETS	544	34.5
Benchmarking against peers	274	17.4
Cost of required measures to achieve emissions reduction targets	378	24.0
Price with material impact on business decisions	188	11.9
Price/cost of voluntary carbon offset credits	326	20.7
Social cost of carbon	151	9.6
Other	212	13.5
What is the goal of implementing this internal carbon price?		
Change internal behavior	973	61.1
Drive energy efficiency	971	61.0
Drive low-carbon investment	1 175	73.8
Identify and seize low-carbon opportunities	829	52.1
Navigate GHG regulations	545	34.2
Reduce supply chain emissions	215	13.5
Set a carbon offset budget	101	6.3
Stakeholder expectations	506	31.8
Stress test investments	368	23.1
Other	83	5.2
Which Scope of carbon emissions is covered?		
Scope 1	1 414	89.2
Scope 2	1 263	79.6
Scope 3 (upstream)	438	27.6
Scope 3 (downstream)	309	19.5
Other	0	0.0
What is the spatial variance approach to internal carbon pricing?		
Differentiated	312	20.1
Uniform	1 211	78.1
Other	31	2.0
What is the temporal variance approach to internal carbon pricing?		
Evolutionary	873	56.1
Static	636	40.8
Other	50	3.2

Source: CDP Questionnaire database (2023) & Authors' calculations.

low-carbon investments and energy efficiency (74% and 61%, respectively). This clearly shows the sustainability preferences of these companies. These two categories are followed by changing internal behavior (61%) and identifying and capturing low-carbon opportunities (52%). The goal of regulation is much lower (34% for navigating GHG regulations and 23% for stress testing investments).

Internal carbon pricing mainly covers Scope 1 and 2 emissions, with 89% and 79% of positive responses, respectively. Scope 3 upstream and downstream emissions are lower (28% and 20%, respectively), consistent with the goal of reducing supply chain emissions when implementing internal carbon pricing. Most ICP programs apply a single price to different business units, with only 20% of companies choosing to differentiate the price by business unit or division. Finally, the majority of companies report that they adjust the internal carbon price over time, while 40% have a static price.

Figure 11: Quantile of minimum and maximum internal carbon prices (global analysis)



Source: CDP Questionnaire database (2023) & Authors' calculations.

In 2022, CDP respondents apply a median carbon price[20] of 51.6$/tCO_2$e. On average, the median minimum price is 38.1$/tCO_2$e while the median maximum price is 65.0$/tCO_2$e. Figure 11 shows the quantile function with respect to the probability α. We observe two regimes: a relatively low slope when α is less than 90% and a high slope after this threshold. This clearly indicates that there are companies with high internal carbon prices that are very different from the rest of the companies. In fact, there is a high heterogeneity between internal carbon prices due to different factors such as country or sector (Table 20). For example, there is a factor of three between the median price in the biotechnology & healthcare sector and the median price in the hospitality sector. Looking at the most carbon-intensive sectors, such as fossil fuels, transportation, and materials, the median carbon price is about 65$/tCO_2$e. In contrast, electricity generation, which is also a carbon-intensive industry, has a median carbon price of 25$/tCO_2$e, one of the lowest sector values.

[20]The carbon price is the average of the minimum and maximum carbon prices.

Table 20: Median value of minimum and maximum internal carbon prices by industry (in $\$/tCO_2e$)

Industry	Minimum		Maximum		Average
	#	$Q_{50\%}$	#	$Q_{50\%}$	$Q_{50\%}$
Biotech & health care	50	60.2	49	89.1	74.7
Fossil fuels	72	41.6	69	100.0	70.8
Transportation services	71	51.3	71	85.6	68.4
Materials	282	50.0	277	76.3	63.1
Manufacturing	301	45.0	300	75.0	60.0
Food & agriculture	82	45.8	82	57.0	51.4
Infrastructure	139	32.1	135	64.2	48.2
Apparel	15	42.8	15	48.8	45.8
Retail	73	29.0	74	52.1	40.6
Services	343	24.2	341	47.3	35.7
Power generation	67	16.7	61	34.0	25.3
Hospitality	7	20.0	7	26.0	23.0
Total	1 502	38.1	1 481	65.0	51.6

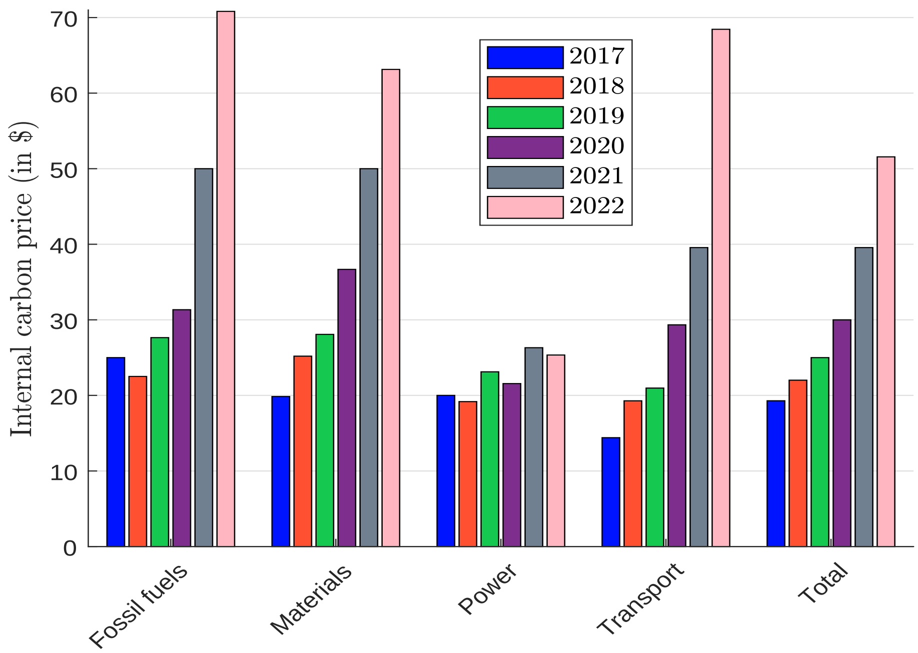
Source: CDP Questionnaire database (2023) & Authors' calculations.

Table 21: Evolution of the median internal carbon price by industry (in $\$/tCO_2e$)

Industry	2017	2018	2019	2020	2021	2022
Apparel	88.2	66.6	82.2	84.6	49.8	45.8
Biotech & health care	55.2	57.3	48.3	73.3	56.9	74.7
Food & agriculture	24.8	21.3	30.0	38.5	46.6	51.4
Fossil fuels	25.0	22.5	27.6	31.3	50.0	70.8
Hospitality	23.2	16.7	15.6	15.1	39.8	23.0
Infrastructure	20.0	23.3	24.6	30.6	35.5	48.2
Manufacturing	19.7	26.3	28.1	36.7	50.6	60.0
Materials	19.8	25.2	28.1	36.7	50.0	63.1
Power generation	20.0	19.2	23.1	21.6	26.3	25.3
Retail	23.9	23.0	24.1	29.3	30.0	40.6
Services	15.6	16.8	16.9	21.7	25.2	35.7
Transportation services	14.4	19.3	21.0	29.3	39.6	68.4
Total	19.3	22.0	25.0	30.0	39.6	51.6

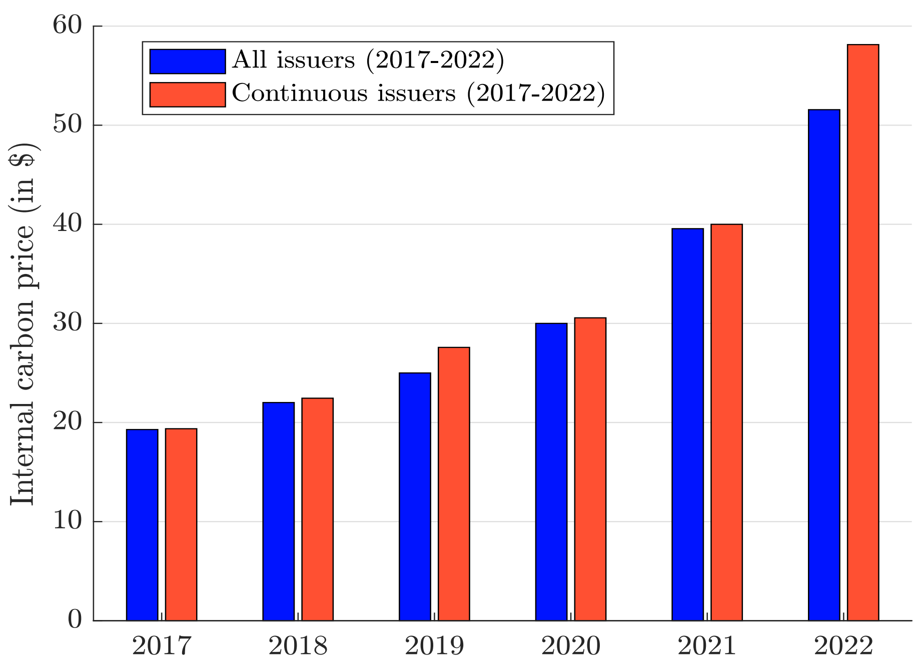
Source: CDP Questionnaire database (2018-2023) & Authors' calculations.

Figure 12: Median internal carbon price (in $\$/tCO_2e$)



Source: CDP Questionnaire database (2018-2023) & Authors' calculations.

Figure 13: Median internal carbon price (in $\$/tCO_2e$) — All issuers vs. continuous issuers



Source: CDP Questionnaire database (2018-2023) & Authors' calculations.

Table 21 shows the evolution of the median internal carbon price between 2017 and 2022. On average, we observe an annual increase of 21.7% from 19.3 to 51.6$/tCO_2$e (Table 38 on page 68). If we look at the sectors, there are four sectors that show an annual increase of more than 20%. These sectors are Transportation, Materials, Manufacturing and Fossil Fuels, which are among the most carbon-intensive sectors. Again, electricity generation shows a curious behavior (Figure 12). Of course, we have to be cautious with these results because there are few observations in some sectors. Also, the population of CDP reporting companies changes from year to year. Nevertheless, if we calculate the median internal carbon price using the continuous issuers that are present in all years from 2017 to 2022, we get a very similar conclusion at the global level (Figure 13).

3.4.4 Relationship between internal and external carbon pricing

In this section, we examine the relationship between internal and external carbon pricing. The goal of this analysis is to identify the key motivations behind the adoption of carbon pricing. Similar to Trinks *et al.* (2022), our approach involves two steps. First, we use a logistic regression model to analyze the likelihood of adopting an internal carbon price based on various characteristics. Second, we use a multivariate regression model to examine the factors that determine the level of carbon pricing among adopters.

The previous section analyzed internal carbon pricing among CDP respondents. However, studying ICP adopters within the CDP database may introduce a selection bias, potentially compromising the external validity of the results. CDP respondents may be more inclined to voluntarily disclose favorable environmental statistics, while non-respondents may not have the same motivation. This selection bias could lead to an overestimation of certain relationships when examining the link between internal and external carbon pricing. To address this potential bias, we restrict our analysis to the sample of companies that are in the MSCI World index at the end of 2022. Of the 1 430 issuers that make up the index, 1 389 were identified in CDP, while 1 181 of these companies provided complete responses to the survey. In total, more than 80% of the largest global companies report to CDP in 2022, accounting for approximately 90% of the total market capitalization of the index. Most of the missing values are concentrated among companies in the financial sector, particularly those based in the United States.

Differences in characteristics between ICP adopters and non-adopters Several factors can influence the adoption of internal carbon pricing and the price level. First, the national environmental policy of the country where the company is located is crucial, especially due to the existence of carbon pricing policies (Bento and Gianfrate, 2020; Trinks *et al.*, 2022). In other words, the influence of external carbon pricing is likely to drive the adoption of an ICP. In addition to CDP information indicating whether a company is subject to external carbon pricing regulations, we assess the stringency of these policies by constructing a national index. Using data from the World Bank (2023) on the coverage, price, and year of implementation of regulations, we create a z-score for different jurisdictions. The environmental policy stringency (EPS) score ranges from -0.83 for Israel to $+1.31$ for Sweden[21].

Firm characteristics, such as firm size, geographic location, environmental rating, or board independence, are also important factors in assessing the likelihood of adopting internal carbon pricing (Bento and Gianfrate, 2020; Trinks *et al.*, 2022). In this analysis, we consider the market origin (*e.g.*, Japan, EMU, or USA), the market capitalization of the company, and the proportion of revenues aligned with green objectives and green taxonomy.

[21] More details on the score can be found in Appendix B.1 on page 69.

In addition, the carbon footprint of the company is also relevant to assess the likelihood of adopting an ICP (Bento and Gianfrate, 2020; Ben-Amar *et al.*, 2022; Trinks *et al.*, 2022). Several metrics are used to capture the carbon intensity of the company and whether it belongs to high emitting sectors (*i.e.*, energy, utilities and, materials).

Before turning to the econometric analysis, we perform a univariate comparison of the means between the groups of ICP adopters and non-adopters of the MSCI World index. The results of this test are presented in Table 22. The sample consists of CDP respondents from the MSCI World Index (1 389 companies), categorized based on their responses regarding the adoption of internal carbon pricing. Companies that are neither considering nor expecting to adopt an ICP are classified as non-adopters. In contrast, adopters are those CDP respondents who have already implemented an ICP. Of the 1 389 matched companies in CDP, there are 480 adopters, 415 non-adopters, 269 companies expecting to adopt in the near future, and 225 missing information. In the latter case, we assume that the company has not adopted an ICP. Although this assumption may be debatable, we interpret non-response as voluntary non-disclosure since these companies are registered in the CDP database.

Table 22: Univariate comparison between adopters and non-adopters of the MSCI World Index (2022) — Two-sample t-test

Variable	Adopters	Non-adopters	t-student	p-value
Number of companies	480	909		
Frequency	0.346	0.654		
Cumulative weights	0.312	0.688		
Environmental policy stringency	0.126	−0.228	10.202***	0.000
Under external pricing (% yes)	0.671	0.300	12.489***	0.000
ETS & CT	0.173	0.051	6.335***	0.000
ETS	0.288	0.123	6.835***	0.000
CT	0.123	0.080	2.368*	0.018
MSCI Japan (% yes)	0.242	0.092	6.849***	0.000
MSCI EMU (% yes)	0.250	0.110	6.265***	0.000
MSCI USA (% yes)	0.219	0.524	−12.133***	0.000
Market capitalization (in $ bn)	42.615	49.623	−0.903	0.367
Green revenue share (in %)	14.152	8.358	4.643***	0.000
Maximum revenue taxonomy (in %)	7.309	4.079	3.817***	0.000
High-emitting sector (% yes)	0.290	0.103	8.075***	0.000
Carbon intensity $\boldsymbol{\mathcal{SC}}_1$	228.488	62.287	5.270***	0.000
Carbon intensity $\boldsymbol{\mathcal{SC}}_2$	37.488	28.379	1.806	0.071
Carbon intensity $\boldsymbol{\mathcal{SC}}_3^{\mathrm{up}}$	143.932	102.555	5.566***	0.000
Carbon intensity $\boldsymbol{\mathcal{SC}}_3^{\mathrm{down}}$	1 252.423	919.514	1.640	0.101

Source: CDP Questionnaire database (2023), MSCI (2024) & Authors' calculations.

In 2022, only one-third of companies in the MSCI World index have an internal carbon pricing system in place. Our EPS score variable suggests that among ICP adopters, the stringency of external carbon pricing regulation tends to be higher than among non-adopters. Similarly, we find that internal carbon pricing systems are more common among companies subject to external carbon pricing mechanisms. Specifically, 67% of ICP adopters are also subject to an external carbon pricing system, compared to only 30% of non-adopters. It is noteworthy that most adopters subject to external carbon pricing are typically under an ETS. Most of the non-adopters are from the US market, while the adopters are fairly distributed among the European, American, and Japanese markets. The average market capitalization is slightly higher for non-adopters than for adopters, although the t-test does not confirm a significant difference in the mean of the groups. This may indicate that company valuation does not seem to be a differentiating factor between adopters and non-adopters. The analysis of means also revealed a clear distinction between adopters and non-adopters in terms of the greenness of their activities. ICP adopters have on average 14.15% and 7.31% of green revenue share and revenue aligned with the green taxonomy, respectively. For non-adopters, the average green revenue share drops to 8.36%, while green taxonomy-aligned revenue is less than 5%. Thus, it is likely that ICP adopters have begun their transition. Finally, the sector analysis shows that 29% of ICP adopters belong to high-emitting sectors (*i.e.*, energy, utilities, and materials), compared to only 10% of non-adopters. In addition, there are significant differences in average Scope 1 and Scope 3 emissions (both upstream and downstream) between adopters and non-adopters, indicating that ICP adopters have generally higher carbon intensities. The most notable difference between the groups is in direct emissions.

Key drivers of ICP adoption While univariate comparisons of means revealed factors that differentiated ICP adopters from non-adopters, the likelihood of adoption should be further explored through a multivariate analysis. To better understand the drivers of ICP adoption, we predict the likelihood of a company implementing an internal carbon price based on a set of predictors. All variables from the univariate analysis are included in the model. Considering the pool of companies that make up the MSCI World index and respond to CDP, we estimate the following logit model:

$$\Pr\left\{Y_i = 1\right\} = \mathbf{F}\left(\beta_0 + \sum\nolimits_{j=1}^{m} \beta_j x_i^{(j)}\right) \tag{1}$$

where $Y_i = 1$ indicates if the company i has adopted an ICP, $\mathbf{F}(z) = \dfrac{e^z}{1+e^z}$ is the cumulative function of the logistic distribution, and $x_i^{(j)}$ is the j^{th} selected variable. The coefficients $\left\{\beta_j, j = 1, \ldots, m\right\}$ are estimated using the maximum likelihood method. Equation (1) can be written as:

$$p_i = \Pr\left\{Y_i = 1\right\}$$

and:

$$\ln\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \sum\nolimits_{j=1}^{m} \beta_j x_i^{(j)}$$

where p_i is the probability of adopting an ICP, and the expression on the left of the equation is the log-odds ratio. If the predicted probability $\hat{p}_i$ is greater than 50%, the model estimates that the firm has adopted an ICP.

In Table 23 we present the results of the logit regression model. Of the 1 181 reporting companies, 22 do not report their emissions, and one company does not report revenue aligned with the green taxonomy. In total, we have 1 172 observations for 2022, which represents approximately 90% of the current market capitalization[22]. When model coefficients are expressed in log-odds format, they can be difficult to interpret. Therefore, we prefer to express the coefficients in odds ratios (*i.e.*, $\hat{\theta}_j = e^{\hat{\beta}_j}$) which are more intuitive to interpret. Thus, a value greater (or lower) than 1 indicates that an increase in the variable increases (or

[22]To ensure that our regression sample is randomly selected, we perform a Heckman test. In this two-step procedure, we first estimate the likelihood of reporting to CDP, which generates an inverse Mills ratio that accounts for sample selection bias. We then include this ratio as an independent variable in the logistic regression model estimating the odds of adopting an ICP. Since the coefficient on the inverse Mills ratio is not statistically significant, we conclude that selection bias is not a concern.

decreases) the probability of adopting an ICP. The t-student and the p-value are estimated on the raw parameters $\hat{\beta}_j$. The explanatory power of the model is represented by the pseudo $\Re^2$ which is similar to the McFadden's likelihood ratio index[23].

Table 23: Logit regression model

Variable	$\hat{\theta}_j$	$\hat{\sigma}\left(\hat{\theta}_j\right)$	t-student	p-value
Intercept	0.009	0.687	-6.908^{***}	0.000
External carbon pricing stringency	1.228	0.189	1.086	0.277
External carbon pricing (ETS & CT)	2.998	0.250	4.390^{***}	0.000
External carbon pricing (ETS)	2.239	0.189	4.258^{***}	0.000
External carbon pricing (CT)	1.789	0.237	2.450^{*}	0.014
MSCI Japan	1.837	0.227	2.676^{**}	0.007
MSCI EMU	1.565	0.215	2.086^{*}	0.037
MSCI USA	0.251	0.267	-5.188^{***}	0.000
MCAP (in logarithm)	1.494	0.069	5.845^{***}	0.000
Green revenue share	1.002	0.004	0.425	0.671
Maximum revenue taxonomy	1.009	0.006	1.317	0.188
High-emitting sector	2.949	0.233	4.648^{***}	0.000
Carbon intensity $\mathcal{SC}_1$	1.001	0.000	3.295^{***}	0.000
Carbon intensity $\mathcal{SC}_2$	0.999	0.001	-0.701	0.483
Carbon intensity $\mathcal{SC}_3$	1.000	0.001	0.655	0.512

$\# = 1\,172$, $\ell\left(\hat{\beta}\right) = -631.63$, $\Re^2 = 20.24$, VIF $= 3.22$

Source: CDP Questionnaire database (2023), MSCI (2024) & Authors' calculations.

Contrary to the univariate comparison of means, the external carbon stringency of the country in which the company is located is not statistically significant. The variation in external carbon stringency does not imply a change in the predicted probability of adopting an ICP. However, being subject to a carbon pricing regulation motivates the adoption of an ICP. The impact appears to be greater for companies subject to both instruments than for those subject to either an ETS or a carbon tax alone. Moreover, the level of statistical significance is lower for firms subject to carbon taxes than for those subject to an ETS, suggesting that ICP adoption is specifically motivated by ETS regulations. Thus, external carbon pricing appears to be the main driver of ICP adoption, but not its stringency. This relationship also reflects the determinant effect of high-emitting sectors. Compared to other companies, companies in the utilities, energy and materials sectors are more likely to implement an ICP. These companies seek to manage the significant risk of additional costs associated with market-based regulation. Other things being equal, the more carbon-intensive a company is, the greater the incentive to implement an internal carbon pricing system. However, this relationship appears to hold only for Scope 1 emissions.

Controlling for the market residence of the issuer, MSCI USA companies are less likely to implement an internal carbon price than companies from other markets. This effect can be explained by the lack of an official carbon pricing system in the United States. As a result, US-based companies are less inclined to implement an ICP system as the prospect of expanding and tightening carbon pricing policies remains to be seen. However, the fact

[23]The McFadden's $\Re^2$ is equal to $\Re^2 = 1 - \frac{\ell\left(\hat{\beta}\right)}{\ell\left(\hat{\beta}_0\right)}$ where $\ell\left(\hat{\beta}\right)$ is the log-likelihood value of the fitted model and $\ell\left(\hat{\beta}_0\right)$ is the log-likelihood value of the intercept model: $\Pr\left\{Y_i = 1\right\} = \mathbf{F}\left(\beta_0\right)$.

that a company operates in the EMU market is not a determining factor in ICP adoption. Although the coefficient is positive, it is not statistically significant at the 95% confidence level. This could be due to the large heterogeneity of environmental regulations in European countries, which are not all at the same level of development. Conversely, companies included in the MSCI Japan are more likely to adopt an ICP, although the estimates are significant at the 95% confidence level.

Firm size, represented by the logarithm of market capitalization (MCAP), appears to be positively related to ICP adoption. All else being equal, the likelihood of adopting an internal carbon pricing system increases as the market valuation of the company increases. Although market capitalization can't be directly linked to the notion of firm size, this positive relationship suggests that the stage of development of the firm tends to alter the likelihood of adopting an ICP. It also sheds light on the promiscuity between ICP adoption and stakeholder pressure. The firm's responsibility for its environmental actions tends to increase as the firm grows. However, neither the green revenue share nor the revenue share aligned with the taxonomy predicts the adoption of an ICP. This could mean that being green does not necessarily motivate the adoption of an ICP. Nevertheless, ICP adopters are on average greener than their counterparts, as previously indicated by the univariate comparison of means. The relationship between ICP adoption and greenness may be inverse.

Table 24: Confusion matrix of the logit regression model

Predicted values / Observed values	ICP adopters	ICP non-adopters	Total
ICP adopters	279	198	477
Implicit price	33	28	61
Internal fee	26	42	68
Shadow price	203	112	315
Other	17	16	33
ICP non-adopters	117	578	695
Total	396	776	1 172

To validate the performance of the previous regression model, we present in Table 24 the confusion matrix of the logit regression. From the fitted values, we determine whether the predictions of the model are in agreement with the observed values. All values $\hat{p}_i$ above the 50% threshold are considered ICP adopters, otherwise they are considered non-adopters. In total, the sample of observations collects 477 adopters for 695 non-adopters. Given the set of explanatory variables, the model predicts the adoption of an ICP for 396 firms and 776 non-adopters. The model is slightly better at predicting non-adopters than adopters, as the 578 true negatives account for 83.2% of accurate predictions of non-adopters, while the 279 true positives account for only 58.5% of accurate predictions of adopters. This may reflect the fact that firms that are unlikely to adopt an ICP are more easily labeled by the model than those that are likely to do so. The accuracy level (*i.e.* the proportion of true negatives and positives to total predictions) of the model is about 73%, meaning that the selected set of variables allows accurate classification of firms as ICP adopters and non-adopters in 73% of cases. For ICP adopters, we can specify the model's predictions by the type of internal carbon pricing mechanism implemented. Shadow pricing is the most common form of ICP in our sample, followed by internal charges and implicit pricing. By comparing the true positive and false negative estimates for each instrument type, we find that the accuracy of the model differs across instrument types. The adoption of shadow pricing systems is predicted relatively more accurately than any other form of carbon pricing. In total, 64% of shadow pricing implementations are efficiently predicted by the model. Conversely, the model has more difficulty predicting internal fee systems, which are misclassified as non-adopters 62% of the time. This may suggest that the profiles of firms that use internal fees and those that use shadow pricing are significantly different, at least given the set of predictors we consider.

The determinants of ICP levels The main drivers for adopting an ICP are based on two fundamental dimensions: external regulation and the company's carbon footprint. Instinctively, the higher a company's carbon footprint, the greater the cost risk associated with external regulation. While the motivations have been identified, we don't know how adopters are pricing carbon. So the question remains: what are the determinants of carbon price levels? To examine the drivers of internal carbon price levels, we specify the following multivariate model:

$$\ln \mathrm{ICP}_i = \beta_0 + \sum_{j=1}^{m} \beta_j x_i^{(j)} + \varepsilon_i \tag{2}$$

where ICP_i is the average internal carbon price of firm i, $x_i^{(j)}$ is the set of m explanatory variables, and ε_i is the error term. The set of variables included in the model is the same as in the logit regression model, except that we also include the type of ICP (shadow price, implicit price, internal fees, or other) to account for the different effects of the type of ICP on the price level. Note also that company carbon intensities are reported on a logarithmic scale.

Table 25: OLS regression model

Variable	$\hat{\beta}_j$	$\hat{\sigma}\left(\hat{\beta}_j\right)$	t-student	p-value
Intercept	4.717	0.678	6.961^{***}	0.000
External carbon pricing stringency	0.519	0.140	3.703^{***}	0.000
External carbon pricing (ETS & CT)	0.526	0.191	2.751^{**}	0.006
External carbon pricing (ETS)	0.471	0.159	2.957^{**}	0.003
External carbon pricing (CT)	−0.104	0.257	−0.404	0.687
Internal carbon pricing (Implicit price)	−0.199	0.267	−0.743	0.458
Internal carbon pricing (Internal fee)	−0.198	0.262	−0.754	0.452
Internal carbon pricing (Shadow pricing)	0.189	0.229	0.824	0.410
MSCI Japan	2.659	0.273	9.735^{***}	0.000
MSCI EMU	−0.549	0.149	-3.694^{***}	0.000
MSCI USA	−0.175	0.202	−0.867	0.387
MCAP (in logarithm)	−0.118	0.055	-2.131^{*}	0.034
Green revenue share	0.003	0.004	0.871	0.384
Maximum revenue taxonomy	0.002	0.005	0.326	0.745
High-emitting sector	−0.110	0.175	−0.629	0.530
Carbon intensity $\boldsymbol{\mathcal{SC}}_1$(in log)	−0.052	0.036	−1.434	0.152
Carbon intensity $\boldsymbol{\mathcal{SC}}_2$(in log)	0.052	0.040	1.296	0.196
Carbon intensity $\boldsymbol{\mathcal{SC}}_3$(in log)	0.075	0.080	0.928	0.354

$\# = 358$, F-statistic $= 12.72^{***}$, $\Re^2 = 38.88$, VIF $= 3.26$

Source: CDP Questionnaire database (2023), MSCI (2024) & Authors' calculations.

The results of the OLS regression model[24] are presented in Table 25. First, we observe the effect of external carbon pricing on ICP levels. The stringency of external carbon pricing systems is positively associated with the internal carbon price set by firms. In other words, the higher the regulatory pressure, the higher the internal carbon price. As a result, promising carbon pricing regulations encourage ICP adopters to raise their own carbon prices. This suggests a possible link between external and internal carbon prices. Although the estimates are statistically significant at the 95% confidence level, the type of instrument to which the firm is subject is also relevant. All else equal, firms subject to both instruments generally set higher carbon prices than firms not subject to external carbon pricing. This effect holds for firms subject only to an ETS, but is ambiguous for firms subject only to carbon taxes.

Regarding the type of ICP, the results are statistically inconclusive, suggesting that the choice of ICP type does not contribute to the determination of price levels. Among the firm characteristics, only market affiliation shows a significant effect. ICP adopters within the MSCI Japan index set relatively higher internal carbon prices compared to those in other markets. Conversely, this relationship is reversed for companies within the EMU market. One possible explanation could be related to the maturity of external pricing policies in these two regions. While Japan's carbon tax covers one of the largest shares of national GHG emissions (around 80% of national GHG emissions), its carbon price is currently one of the lowest (around \$2/tCO_2e in 2022). Therefore, Japanese companies can expect external carbon prices to rise in the coming years. In contrast, the European carbon market is more mature, with a higher price (around \$86/tCO_2e in 2022) and fair emissions coverage (around 40% of EU emissions). European companies may have more confidence in the stability of the future carbon price path than Japanese companies, reducing the incentive for a significant carbon price in this region. Another explanation could be the large heterogeneity of regulations across European countries, which are at different stages of development. Finally, the results show that the coefficients related to the company's carbon footprint are not statistically significant. Despite being an important determinant of ICP adoption, high emitting sectors do not necessarily apply higher carbon prices. Overall, the results show that external carbon pricing policies are the main drivers of internal carbon pricing.

4 Conclusion

This study provides an introduction to carbon pricing mechanisms. In the first section, we provide a global overview of existing carbon pricing regulations, drawing on official reports from the World Bank (2023) and ICAP (2023). We examine and compare ETS and carbon taxes in terms of GHG emissions coverage, carbon price structure, and revenue generation. This analysis shows that, despite a positive trend, market-based instruments fall short of the development needed to facilitate a gradual transition to a net-zero economy. While countries with implemented carbon pricing policies account for more than 70% of global GDP and about 60% of GHG emissions, only an estimated 23% of global GHG emissions are effectively regulated by a carbon pricing mechanism in 2023. In terms of price, 90% of existing systems set a carbon price between \$0 and \$25/tCO_2e. In general, most carbon pricing policies systematically lack broad coverage or a high price. This imbalance highlights the need to tighten rather than proliferate these policies.

[24] Of the 480 ICP adopters, 447 companies reported a non-zero carbon price. However, some of the reported figures are unusually high. Therefore, observations with a carbon price above \$2 000/tCO_2e are excluded from the data set. As a result, the analysis is only performed on 358 observations.

In the second part of the study, we examine firm-level carbon pricing data from the Carbon Disclosure Project database (CDP, 2023). We retrieve the database as of October 2023 and analyze the different fields of the questionnaire, in particular section C11, which is dedicated to carbon pricing. Among the respondents, 27% are under an external carbon pricing scheme and 26% have implemented an internal carbon price (ICP). Notably, only 13% of regulated companies have implemented an internal carbon price, suggesting that half of regulated companies are not passing on external carbon costs to their internal operations. After adjusting for survival and universe biases, we find that ICP adoption has been relatively limited and unstable in recent years. Many companies that commit to future adoption by stating in the questionnaire that ICP implementation is imminent have yet to take action. Potentially, communication about ICP adoption can lead to a free-rider problem, exacerbating concerns about greenwashing. For instance, less than 30% of companies that promise to implement internal carbon pricing within two years actually do so within that timeframe, and this figure rises to less than 50% within five years.

We further explore the drivers of ICP adoption and ICP levels using econometric regressions. Among companies in the MSCI World Index, those subject to external carbon pricing, particularly through ETS, and those in highly carbon-intensive industries are more likely to adopt an ICP. These companies, which face significant risks from external regulation, rationally seek to manage the additional carbon costs induced by such policies. In terms of internal carbon price levels, the presence and stringency of external carbon pricing emerge as the most important factors, both of which are positively associated with higher ICP levels. In contrast to ICP adoption, corporate carbon footprint does not appear to be a driver of ICP levels. Overall, our results highlight a strong link between external and internal carbon pricing.

The results so far suggest that corporate data on carbon pricing is incomplete and of questionable quality. In terms of representativeness, only 40% of the companies that received the questionnaire responded rigorously, limiting the external validity of this analysis. In terms of data quality, many reported figures are either unusually high or unusually low, leading to inflated estimates due to double counting and other inconsistencies that distort key metrics. In addition, some influential companies with significant carbon footprints either do not respond to the questionnaire or provide only partial information, undermining the accuracy of more specific analyses. As a result, it is important to treat the data with caution and avoid over-interpreting the results. This is especially true for ESG analysts who use this data in their ESG scoring models. Data needs to be challenged.

Another important implication of this study relates to net-zero investment policies. In order to consider climate risks and allocate capital in an optimal way, fund managers must use net-zero climate metrics. By definition, assessing the dynamics of carbon and green footprints for companies is essential (Roncalli, 2024b). Carbon pricing is also an important component of a net-zero investment policy, as carbon pricing is the backbone of the transition risk. Since we do not observe a major shift in the adoption of internal carbon pricing, our study suggests that few companies currently anticipate a shift in the stringency of external carbon pricing. These findings are disappointing, especially in the extensive attention generated by the Glasgow COP26 and the launch of the GFANZ initiative. They also raise questions about the credibility of companies' pledges and announced targets, as the current dynamics of carbon pricing (both external and internal) are unfortunately not sufficient to provide a secure pathway to a low-carbon economy by 2050.

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A Additional results

A.1 Tables and figures

Table 26: Carbon pricing programs around the world

Status	CT	ETS	Total
Implemented (1)	37	38	75
Regional	0	2	2
National	27	13	40
Subnational	10	23	33
Under development (2)	1	9	10
Under consideration (3)	13	20	33
Abolished (0)	4	3	7
Total	55	70	125

We use the following codes for the status shown in the next two tables: (0) if the carbon tax program is cancelled, (1) if the carbon tax program is implemented, (2) if the carbon tax program is under development, and (3) if the carbon tax program is under consideration.

Source: CDP (2023), ICAP (2023), World Bank (2023) & Authors' calculations.

Table 27: Carbon tax programs around the world

Region	Name	Country	Type	World Bank	CDP	Status	Year
Europe	Catalonia CT	Spain	Subnational	✓		3	
	Denmark CT	Denmark	National	✓	✓	1	1992
	Estonia CT	Estonia	National	✓	✓	1	2000
	Finland CT	Finland	National	✓	✓	1	1990
	France CT	France	National	✓	✓	1	2014
	Iceland CT	Iceland	National	✓	✓	1	2010
	Ireland CT	Ireland	National	✓	✓	1	2010
	Latvia CT	Latvia	National	✓	✓	1	2004
	Liechtenstein CT	Liechtenstein	National	✓	✓	1	2008
	Luxembourg CT	Luxembourg	National	✓	✓	1	2021
	Netherlands CT	Netherlands	National	✓	✓	1	2021
	Norway CT	Norway	National	✓	✓	1	1991
	Poland CT	Poland	National		✓	1	1990
	Portugal CT	Portugal	National	✓	✓	1	2015
	Slovenia CT	Slovenia	National		✓	0	1996
	Spain CT	Spain	National	✓	✓	1	2014
	Sweden CT	Sweden	National	✓	✓	1	1991
	Switzerland CT	Switzerland	National	✓	✓	1	2008
	UK CPS	United Kingdom	National	✓	✓	1	2013
	Ukraine CT	Ukraine	National	✓	✓	1	2011

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Table 27: Carbon tax programs around the world

Continued from previous page

Region	Name	Country	Type	World Bank	CDP	Status	Year
North America	Alberta CT	Canada	Subnational	✓		0	2017
	Bristish Columbia CT	Canada	Subnational		✓	1	2008
	Canada Federal Fuel Charge	Canada	National	✓	✓	1	2019
	Manitoba CT	Canada	Subnational			3	
	New Brunswick CT	Canada	Subnational		✓	1	2020
	Newfoundland/Labrador CT	Canada	Subnational	✓	✓	1	2019
	Northwest Territories CT	Canada	Subnational		✓	1	2019
	Prince Edward Island CT	Canada	Subnational	✓	✓	1	2019
	Hawaii CT	USA	Subnational			3	
Latin America	Argentina CT	Argentina	National	✓	✓	1	2018
	Chile CT	Chile	National	✓	✓	1	2017
	Colombia CT	Colombia	National	✓	✓	1	2017
	Baja California CT	Mexico	Subnational	✓	✓	0	2020
	Durango CT	Mexico	Subnational	✓		1	2022
	Guanajuato CT	Mexico	Subnational			2	
	Jalisco CT	Mexico	Subnational	✓		3	
	Mexico National CT	Mexico	National	✓	✓	1	2014
	Queretaro CT	Mexico	Subnational	✓		1	2022
	State of Mexico CT	Mexico	Subnational	✓		1	2022
	Tamaulipas CT	Mexico	Subnational		✓	0	2023
	Yucatan CT	Mexico	Subnational	✓		1	2022
	Zacatecas CT	Mexico	Subnational	✓	✓	1	2021
	Uruguay CO2 Tax	Uruguay	National	✓	✓	1	2022
Africa	Botswana CT	Botswana	National	✓		3	
	Israel CT	Israel	National	✓		3	
	Ivory Coast CT	Ivory Coast	National	✓		3	
	Morocco CT	Morocco	National	✓		3	
	Senegal CT	Senegal	National			3	
	South Africa CT	South Africa	National	✓	✓	1	2019
Asia	Brunei CT	Brunei	National	✓		3	
	Indonesia CT	Indonesia	National			3	
	Japan CT	Japan	National	✓	✓	1	2012
	New Zealand Agriculture CT	New Zealand	National			3	
	Singapore CT	Singapore	National	✓	✓	1	2019
	Taiwan Carbon Fee	Taiwan	National			3	

Source: CDP (2023), ICAP (2023), World Bank (2023) & Authors' calculations.

Table 28: ETS programs around the world

Region	Name	Country	Type	World Bank	ICAP	CDP	Status	Year
Europe	EU ETS	European Union	Regional	✓	✓	✓	1	2005
	EU ETS 2	European Union	Regional	✓	✓		2	2027
	Albania ETS	Albania	National	✓			3	
	Austria ETS	Austria	National	✓	✓		1	2022
	Bosnia/Herzegovina ETS	Bosnia/Herzegovina	National	✓			3	
	Germany ETS	Germany	National	✓	✓	✓	1	2021
	Kazakhstan ETS	Kazakhstan	National	✓	✓	✓	1	2013
	Moldova ETS	Moldova	National	✓			3	
	Montenegro ETS	Montenegro	National	✓	✓		1	2022
	North Macedonia ETS	North Macedonia	National	✓			3	
	Sakhalin	Russia	Subnational	✓	✓		2	2024
	Serbia ETS	Serbia	National	✓			3	
	Switzerland ETS	Switzerland	National	✓	✓	✓	1	2008
	Türkiye pilot ETS	Turkey	National	✓	✓		2	2024
	UK ETS	United Kingdom	National	✓	✓	✓	1	2021
	Ukraine ETS	Ukraine	National	✓	✓		2	2025
North America	Canada Federal OBPS	Canada	National	✓	✓	✓	1	2019
	Alberta TIER	Canada	Subnational	✓		✓	1	2019
	Bristish Columbia ETS	Canada	Subnational	✓		✓	1	2019
	Manitoba ETS	Canada	Subnational	✓			3	
	New Brunswick ETS	Canada	Subnational	✓		✓	1	2019
	Newfoundland/Labrador PSS	Canada	Subnational	✓		✓	1	2019
	Nova Scotia CaT	Canada	Subnational	✓	✓	✓	0	2019
	Nova Scotia OBPS	Canada	Subnational	✓	✓	✓	1	2023
	Ontario CAT	Canada	Subnational	✓		✓	0	2017
	Ontario EPS	Canada	Subnational	✓		✓	1	2022
	Québec CaT	Canada	Subnational	✓	✓	✓	1	2013
	Saskatchewan OBPS	Canada	Subnational	✓		✓	1	2019
	California CaT	USA	Subnational	✓	✓	✓	1	2012
	Massachusetts ETS	USA	Subnational	✓	✓	✓	1	2022
	New York City ETS	USA	Subnational		✓		3	
	New York State ETS	USA	Subnational	✓	✓		2	2024
	North Carolina ETS	USA	Subnational	✓	✓		3	
	Oregon ETS	USA	Subnational	✓	✓	✓	1	2022
	Pennsylvania ETS	USA	Subnational	✓	✓		2	2024
	RGGI	USA	Subnational	✓	✓	✓	1	2023
	Washington CaT/CCA	USA	Subnational	✓	✓	✓	1	2023
Latam	Brazil ETS	Brazil	National	✓	✓		3	
	Chile ETS	Chile	National		✓		3	
	Colombia pilot ETS	Colombia	National		✓		2	2030
	Mexico pilot ETS	Mexico	National	✓	✓	✓	1	2020
	Renovabio	Brazil	National			✓	1	2017

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Source: CDP (2023), ICAP (2023), World Bank (2023) & Authors' calculations.

Table 28: ETS programs around the world

Continued from previous page

Region	Name	Country	Type	World Bank	ICAP	CDP	Status	Year
Africa	Gabon ETS	Gabon	National	✓			3	
	Nigeria ETS	Nigeria	National	✓	✓		3	
Asia	Australia CPM	Australia	National	✓			0	2012
	Australia ETS	Australia	National	✓		✓	1	2016
	Beijing pilot ETS	China	Subnational	✓	✓	✓	1	2013
	Brunei ETS	Brunei	National	✓			3	
	China National ETS	China	National	✓	✓	✓	1	2021
	Chongqing pilot ETS	China	Subnational	✓	✓	✓	1	2014
	Fujian pilot ETS	China	Subnational	✓	✓	✓	1	2016
	Guangdong pilot ETS	China	Subnational	✓	✓	✓	1	2013
	Hubei pilot ETS	China	Subnational	✓	✓	✓	1	2014
	Shanghai pilot ETS	China	Subnational	✓	✓	✓	1	2013
	Shenzhen pilot ETS	China	Subnational	✓	✓	✓	1	2013
	Tianjin pilot ETS	China	Subnational	✓	✓	✓	1	2013
	Georgia ETS	Georgia	National	✓			3	
	India ETS	India	National	✓	✓		3	
	Indonesia ETS	Indonesia	National	✓	✓		2	2025
	Japan ETS	Japan	National	✓	✓		3	
	Saitama ETS	Japan	Subnational	✓	✓	✓	1	2011
	Tokyo CaT	Japan	Subnational	✓	✓	✓	1	2010
	Malaysia ETS	Malaysia	National	✓	✓		3	
	New Zealand ETS	New Zealand	National	✓	✓	✓	1	2008
	Pakistan ETS	Pakistan	National		✓		3	
	Korea ETS	South Korea	National	✓	✓	✓	1	2015
	Taiwan ETS	Taiwan	National	✓	✓		3	
	Thailand pilot ETS	Thailand	National	✓	✓		3	
	Vietnam pilot ETS	Vietnam	National	✓	✓		2	2026
World	Corsia	Intern. Aviation	Regional	✓	✓		1	2021

Source: CDP (2023), ICAP (2023), World Bank (2023) & Authors' calculations.

Table 29: Historical share (in %) of free allowances relative to verified emissions

Year	Aviation	Fossil fuel combustion	Ferrous materials	Cement & lime	Non-ferrous materials	Pulp & paper	Chemicals	Carbon capture	Stationary	Industrial
	Sectors								All	
2005		100%	114%	104%	108%	114%	111%	142%	102%	108%
2006		99%	109%	102%	107%	111%	111%	138%	101%	105%
2007		98%	109%	100%	107%	115%	112%	144%	100%	105%
2008		92%	119%	106%	110%	112%	107%	127%	96%	108%
2009		96%	147%	120%	125%	121%	117%	153%	102%	122%
2010		96%	133%	120%	125%	117%	112%	133%	102%	119%
2011		97%	133%	120%	123%	120%	114%	157%	103%	120%
2012	154%	99%	136%	126%	128%	125%	118%	162%	105%	124%
2013	60%	66%	113%	110%	100%	111%	106%	120%	77%	105%
2014	86%	66%	111%	103%	98%	112%	106%	116%	76%	103%
2015	78%	64%	110%	103%	96%	109%	102%	109%	74%	102%
2016	76%	63%	110%	103%	95%	108%	102%	104%	74%	101%
2017	75%	62%	109%	100%	93%	105%	100%	100%	72%	100%
2018	72%	61%	107%	98%	92%	104%	100%	97%	72%	99%
2019	72%	62%	109%	99%	92%	104%	100%	104%	74%	99%
2020	110%	62%	115%	101%	93%	106%	100%	111%	75%	102%
2021	93%	59%	105%	92%	85%	100%	97%	111%	70%	95%
2022	73%	58%	111%	95%	87%	105%	107%	103%	71%	97%

Fuel combustion primarily includes electricity generation and several manufacturing industries. The production of raw materials includes activities related to iron, steel, metal, ores, primary and secondary aluminum, ferrous and non-ferrous materials, cement, and lime production. Chemical manufacturing includes activities related to pulp, hydrogen, glyoxal, or bulk chemicals, for example. Manufacturing includes activities related to the production of non-metallic minerals, such as glass, ceramics, and mineral wool.

Source: EUTL (2023), & Authors' calculations.

Table 30: Historical carbon tax price (in $\$/tCO_2e$)

	Carbon tax program	2010	2015	2019	2020	2021	2022	2023
National	Argentina			6.2	5.9	5.5	5.0	3.3
	Canada federal fuel charge			15.0	21.1	31.8	40.0	48.0
	Chile			5.0	5.0	5.0	5.0	5.0
	Colombia			5.2	4.2	5.0	5.0	5.1
	Denmark	28.0	24.5	26.4	25.9	28.1	26.6	26.5
	Estonia	2.7	2.2	2.2	2.2	2.3	2.2	2.2
	Finland	27.5	62.4	69.7	67.8	72.8	85.1	83.7
	France		15.6	50.1	48.8	52.4	49.3	48.5
	Iceland	8.5	16.0	31.3	29.9	34.8	34.2	38.5
	Ireland	20.2	21.5	22.5	28.4	39.3	45.3	52.7
	Japan		1.6	2.6	2.7	2.6	2.4	2.2
	Latvia	0.8	3.8	5.1	9.8	14.1	16.6	16.3
	Liechtenstein	34.2	37.2	96.5	99.4	101.5	129.9	130.8
	Luxembourg					40.1	43.3	48.1
	Mexico		3.2	3.0	2.4	3.2	3.7	4.1
	Netherlands					35.2	46.1	55.6
	Norway	62.0	54.0	59.2	52.9	69.3	87.6	90.9
	Poland	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Portugal		5.5	14.3	25.8	28.2	26.4	26.0
	Singapore			3.7	3.5	3.7	3.7	3.8
	South Africa				7.1	9.2	9.8	8.9
	Spain		21.5	16.9	16.4	17.6	16.6	16.3
	Sweden	145.5	129.8	126.8	119.4	137.2	129.9	125.6
	Switzerland	34.2	62.0	96.5	99.4	101.5	129.9	130.8
	UK CPS		26.7	23.6	22.3	24.8	23.7	22.3
	Ukraine		0.0	0.4	0.4	0.4	1.0	0.8
	Uruguay						137.3	155.9
Regional	Canada							
	British Columbia	19.9	23.8	30.0	28.1	35.8	40.0	48.0
	New Brunswick				21.1	31.8	40.0	48.0
	Newfoundland/Labrador			15.0	14.1	23.9	40.0	48.0
	Northwest Territories				14.1	23.9	32.0	48.0
	Prince Edward Island			15.0	21.1	23.9	24.0	36.9
	Mexico							
	Zacatecas			13.0	11.8	12.2	12.6	13.9
	Average	32.0	26.9	28.0	27.0	31.8	39.2	42.3
	Median	23.8	21.5	15.0	18.8	24.3	26.6	36.9
	Top five	60.8	69.1	89.7	87.8	96.5	122.9	126.8

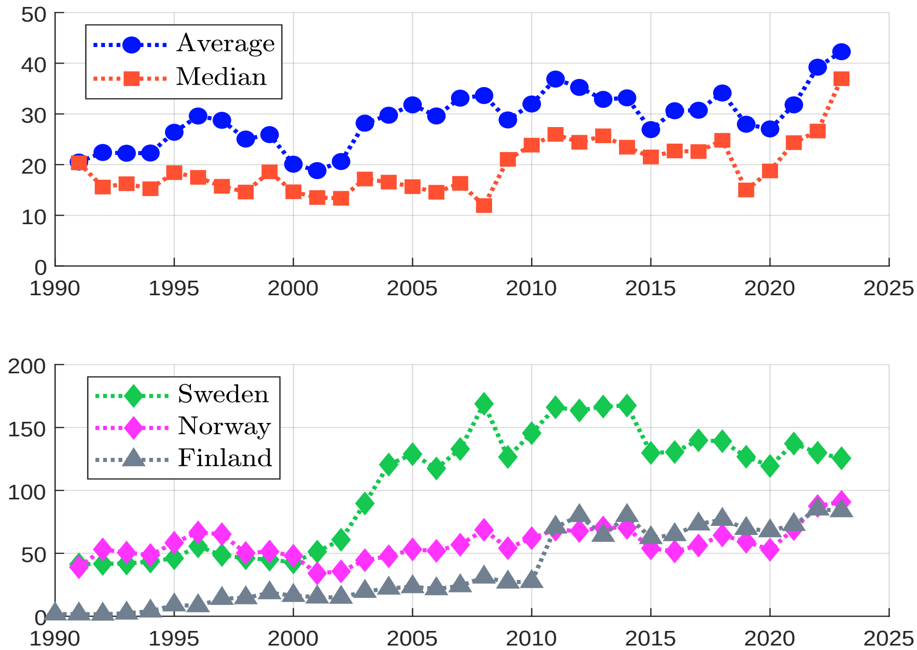
Source: World Bank (2023) & Authors' calculations.

Table 31: Historical ETS price (in \$/tCO_2e)

	Carbon tax program	2010	2015	2019	2020	2021	2022	2023
National	Australia				10.2	12.0	11.9	10.6
	Austria							35.3
	Canada federal OBPS					31.8	40.0	48.0
	China national						9.2	8.2
	EU ETS	17.3	7.7	24.5	18.5	49.8	86.5	96.3
	Germany					29.4	33.2	32.6
	Kazakhstan		2.0		1.1	1.2	1.1	1.1
	New Zealand	12.4	4.9	17.5	14.3	25.8	52.6	34.2
	South Korea		9.1	23.5	32.8	15.9	18.7	11.2
	Switzerland		12.4	7.2	18.8	41.5	64.2	93.8
	UK ETS						99.0	88.1
Regional	Canada							
	Alberta TIER	14.9	11.9	22.5	21.1	31.8	40.0	48.0
	British Columbia					19.9	20.0	18.5
	New Brunswick						40.0	48.0
	Newfoundland/Labrador PSS					23.9	40.0	48.0
	Nova Scotia					19.7	23.1	20.9
	Ontario EPS						32.0	48.0
	Quebec		12.5	15.8	15.3	17.9	30.8	29.8
	Saskatchewan OBPS					31.8	40.0	48.0
	China							
	Beijing pilot		8.2	10.4	12.2	4.3	6.5	13.0
	Chongqing pilot		3.9	0.6	5.3	3.7	5.7	4.7
	Fujian pilot			1.5	1.3	1.2	1.8	4.7
	Guangdong pilot		5.5	2.9	4.1	5.7	12.5	12.3
	Hubei pilot		4.2	4.1	3.6	4.4	7.2	7.0
	Shanghai pilot		4.7	6.1	5.1	6.3	9.3	8.7
	Shenzhen pilot		6.0	0.6	2.4	1.1	0.6	8.8
	Tianjin pilot		4.2	2.1	2.8	3.8	4.4	4.6
	Japan							
	Saitama		37.5	5.9	5.6	5.4	3.8	1.1
	Tokyo		37.5	5.9	5.6	4.9	4.4	42.0
	USA							
	California		12.5	15.8	15.3	17.9	30.8	29.8
	Massachusetts				8.2	6.5	0.5	12.1
	RGGI	2.3	5.9	4.9	5.1	8.7	13.9	15.4
	Washington CCA							22.2
	Average	11.7	10.6	9.5	9.9	15.8	25.3	28.9
	Median	13.7	6.8	6.0	5.6	12.0	18.7	20.9
	Top 5		22.5	20.8	21.3	37.4	68.5	74.9

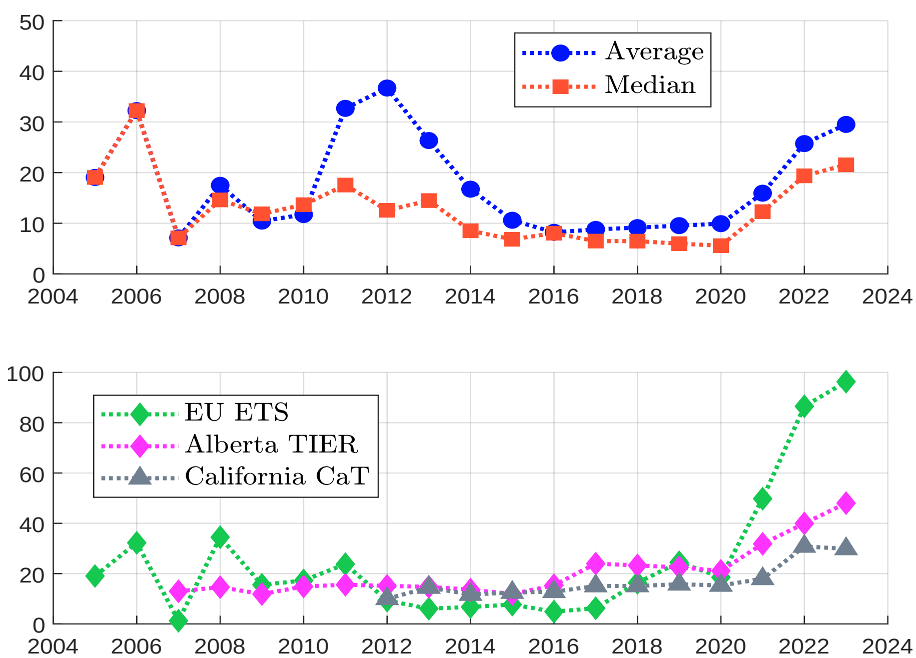
Source: World Bank (2023) & Authors' calculations.

Figure 14: Price evolution of carbon taxes



Source: World Bank (2023) & Authors' calculations.

Figure 15: Price evolution in emissions trading systems



Source: World Bank (2023) & Authors' calculations.

Table 32: ETS statistics from CDP reporting companies (number of companies and Scope 1 emissions covered by ETS)

Name	#	Mean	Min	$Q_{25\%}$	$Q_{50\%}$	$Q_{75\%}$	Max
EU ETS	403	45.8	0.01	10.8	35.0	87.4	100.0
UK ETS	122	25.8	0.01	1.7	7.3	35.0	100.0
Korea ETS	116	69.0	0.01	28.5	97.5	100.0	100.0
Tokyo CaT	89	22.3	0.01	1.0	7.0	26.3	100.0
Saitama ETS	51	21.3	0.01	1.6	6.5	24.3	100.0
California CaT	47	26.2	0.05	2.0	8.0	31.5	100.0
Alberta TIER	39	35.1	0.05	3.3	23.1	60.0	100.0
Shenzhen pilot ETS	33	27.0	0.11	0.9	2.6	52.0	100.0
Québec CaT	33	22.5	0.01	1.1	6.0	28.0	100.0
Shanghai pilot ETS	28	30.0	0.01	0.9	3.7	59.0	100.0
Ontario EPS	26	33.5	0.18	5.0	18.0	38.0	100.0
Other ETS	23	63.9	2.00	14.5	94.4	99.9	100.0
Canada Federal OBPS	23	47.4	0.07	3.6	33.9	100.0	100.0
Beijing pilot ETS	21	17.3	0.01	0.7	4.7	20.5	100.0
Switzerland ETS	21	10.6	0.03	0.5	2.0	3.0	100.0
Australia ETS	20	65.2	4.92	24.8	81.0	97.0	100.0
China National ETS	16	51.0	0.34	14.0	41.5	99.5	100.0
Germany ETS	16	22.7	0.80	2.0	4.4	18.9	100.0
Saskatchewan OBPS	14	20.8	0.42	2.1	5.7	29.0	100.0
Mexico pilot ETS	13	55.0	13.00	34.8	43.5	78.0	100.0
New Zealand ETS	11	77.3	0.42	76.9	95.0	100.0	100.0
RGGI	11	30.1	0.10	0.4	11.8	64.9	100.0
Kazakhstan ETS	8	83.0	1.18	81.5	99.8	100.0	100.0
Tianjin pilot ETS	7	22.4	0.13	1.0	11.0	23.9	100.0
Oregon ETS	5	9.2	2.00	2.7	10.0	12.8	21.0
Chongqing pilot ETS	4	36.6	0.32	4.2	23.1	69.1	100.0
Hubei pilot ETS	4	23.5	3.56	3.9	20.1	43.1	50.2
Washington CaT/CCA	4	19.7	2.80	2.9	18.5	36.5	39.0
Fujian pilot ETS	3	29.5	2.46	3.3	6.0	61.5	80.0
Nova Scotia CaT	3	13.4	0.09	0.3	1.0	29.5	39.0
Guangdong pilot ETS	3	1.7	1.10	1.2	1.5	2.3	2.6
Newfoundland/Labrador PSS	2	50.0					
British Columbia ETS	2	20.0					
Massachusetts ETS	2	4.8					
New Brunswick ETS	1	99.0					
Total	1 224	39.2	0.01	3.0	21.6	86.3	100.0

Source: CDP Questionnaire database (2023) & Authors' calculations.

Table 33: ETS statistics from CDP reporting companies (number of companies and Scope 2 emissions covered by ETS)

Name	#	Mean	Min	$Q_{25\%}$	$Q_{50\%}$	$Q_{75\%}$	Max
Korea ETS	112	75.1	0.29	51.8	99.5	100.0	100.0
Tokyo CaT	97	32.9	0.01	3.8	14.0	55.2	100.0
Saitama ETS	51	25.7	0.05	3.0	7.7	19.8	100.0
EU ETS	41	42.2	0.00	9.0	35.0	83.1	100.0
Shenzhen pilot ETS	34	52.5	0.46	5.0	41.5	99.7	100.0
Shanghai pilot ETS	29	43.8	0.03	2.6	19.0	100.0	100.0
Beijing pilot ETS	27	18.8	0.03	1.1	3.9	22.6	100.0
Alberta TIER	17	48.7	0.60	6.2	48.1	100.0	100.0
UK ETS	13	38.4	0.10	3.2	18.0	92.5	100.0
China National ETS	12	47.7	0.00	3.7	33.6	99.8	100.0
Other ETS	10	60.0	0.10	2.3	97.4	100.0	100.0
California CaT	8	37.2	0.06	2.5	17.1	79.0	100.0
Tianjin pilot ETS	8	30.3	0.87	3.8	17.0	50.1	100.0
Hubei pilot ETS	4	56.7	1.08	24.9	62.9	88.5	100.0
Québec CaT	4	50.4	0.01	0.8	50.8	100.0	100.0
Chongqing pilot ETS	4	30.4	0.57	4.0	10.6	56.8	100.0
Fujian pilot ETS	4	12.0	0.70	1.1	10.7	23.0	26.0
Guangdong pilot ETS	4	2.1	0.90	0.9	1.1	3.2	5.1
Kazakhstan ETS	3	100.0	100.00	100.0	100.0	100.0	100.0
Canada Federal OBPS	3	67.3	2.00	26.5	100.0	100.0	100.0
Switzerland ETS	3	37.4	0.08	3.1	12.0	78.0	100.0
Oregon ETS	3	15.7	10.00	10.0	10.0	22.8	27.0
Ontario EPS	3	0.5	0.02	0.1	0.4	0.8	1.0
Germany ETS	2	48.8					
Saskatchewan OBPS	2	16.4					
New Zealand ETS	1	100.0					
RGGI	1	100.0					
Washington CaT/CCA	1	26.0					
Total	501	45.7	0.00	4.3	29.7	99.8	100.0

Source: CDP Questionnaire database (2023) & Authors' calculations.

Table 34: ETS statistics from CDP reporting companies (Covered and verified emissions)

Name	Covered emissions $\mathcal{SC}_{1-2}$	$\mathcal{SC}_1$	$\mathcal{SC}_2$	Verified emissions $\mathcal{SC}_1$	$\mathcal{SC}_2$	$\mathcal{SC}_1$	$\mathcal{SC}_2$
	(in $MtCO_2e$)			(in $MtCO_2e$)		(in %)	
EU ETS	1 271.2	1 257.4	13.8	979.5	9.6	77.9	69.7
Korea ETS	360.8	293.2	67.6	283.4	60.9	96.6	90.0
Other ETS	253.5	240.3	13.2	263.4	1.1	109.6	8.7
UK ETS	187.1	182.0	5.2	83.9	0.5	46.1	10.3
Québec CaT	174.3	168.1	6.2	6.0	0.0	3.6	0.3
Mexico pilot ETS	147.9	147.9		37.4		25.3	
Alberta TIER	138.5	125.3	13.2	94.0	4.4	75.0	33.3
Kazakhstan ETS	136.7	134.5	2.2	25.2	0.1	18.7	2.8
Australia ETS	122.5	122.5		231.7	0.6	189.2	
RGGI	90.8	90.7	0.2	46.9	0.0	51.8	0.0
California CaT	85.1	83.8	1.2	41.7	1.0	49.7	77.9
China national ETS	73.6	68.6	5.0	31.7	0.9	46.2	17.3
Ontario EPS	62.9	62.8	0.1	8.8	0.0	14.0	13.4
Shanghai pilot ETS	39.7	6.3	33.4	1.6	2.6	25.0	7.6
Newfoundland/Labrador PSS	33.5	33.5		0.0		0.1	
New Zealand ETS	30.5	30.5	0.0	3.9	0.0	12.7	449.7
Canada federal OBPS	30.5	26.8	3.7	3.8	0.0	14.2	1.1
Hubei pilot ETS	23.4	20.9	2.5	0.0	0.6	0.1	23.2
Tokyo CaT	21.4	4.8	16.5	0.8	3.4	17.5	20.8
Saitama ETS	15.1	7.6	7.5	0.9	0.6	11.5	8.3
Shenzhen pilot ETS	12.3	0.2	12.0	0.1	6.7	37.6	56.0
Beijing pilot ETS	11.0	0.9	10.1	0.5	3.9	58.2	38.1
Nova Scotia CaT	5.9	5.9		5.9		99.3	
Chongqing pilot ETS	5.0	3.6	1.4	0.0	0.1	0.8	8.2
Washington CaT/CCA	5.0	4.9	0.1	4.2	0.1	85.6	98.2
Saskatchewan OBPS	4.7	4.2	0.4	4.0	0.4	94.4	93.3
Switzerland ETS	4.1	4.0	0.1	26.1	0.1	651.2	79.1
Tianjin pilot ETS	3.4	0.8	2.6	0.6	1.0	73.6	39.9
Germany ETS	2.4	1.2	1.2	1.2	1.3	99.9	107.7
Oregon ETS	2.2	1.9	0.3	0.5	0.1	27.8	30.3
Massachusetts ETS	1.9	1.9		1.9		101.0	
Fujian pilot ETS	1.6	1.0	0.7	0.4	0.5	45.7	72.8
British Columbia ETS	1.6	1.6		1.5		94.3	
New Brunswick ETS	0.9	0.9		0.0		3.1	
Guangdong pilot ETS	0.8	0.6	0.1	0.0	0.0	1.4	21.9
Total	3 362.0	3 141.3	220.7	2 191.6	100.7	69.8	45.6

Source: CDP Questionnaire database (2023) & Authors' calculations.

Table 35: EU ETS statistics by industry in 2022 (covered emissions, verified emissions and allowances in $MtCO_2e$)

Industry	#	Covered			Verified	Carbon allowances	
		$\mathcal{SC}_{1-2}$	$\mathcal{SC}_1$	$\mathcal{SC}_2$	$\mathcal{SC}_{1-2}$	Alloc.	Bought
Materials	133	592.6	582.2	10.5	293.2	245.2	29.2
Power generation	19	211.7	211.7	0.0	187.6	34.6	157.0
Infrastructure	34	208.6	208.5	0.1	220.4	4.3	190.3
Fossil fuels	27	150.1	149.7	0.4	163.1	87.0	65.5
Transportation services	23	41.8	41.8	0.1	74.1	15.6	18.8
Manufacturing	75	20.9	19.7	1.1	15.8	11.2	6.1
Retail	7	19.6	19.1	0.4	19.2	16.9	2.0
Food & agriculture	36	13.8	12.6	1.2	9.8	3.9	3.1
Services	20	9.8	9.8	0.0	4.2	3.5	0.2
Biotech & health care	30	2.3	2.3	0.0	1.7	0.9	0.8
Apparel	1	0.0	0.0	0.0	0.0	0.0	0.0
Total	405	1 271.2	1 257.4	13.8	989.1	423.0	472.9

Source: CDP Questionnaire database (2023) & Authors' calculations.

Table 36: Non-EU ETS statistics by industry in 2022 (covered emissions, verified emissions and allowances in $MtCO_2e$)

Industry	#	Covered			Verified	Carbon allowances	
		$\mathcal{SC}_{1-2}$	$\mathcal{SC}_1$	$\mathcal{SC}_2$	$\mathcal{SC}_{1-2}$	Alloc.	Bought
Materials	143	928.2	859.4	68.7	262.7	284.1	6.3
Fossil fuels	42	487.3	468.2	19.1	375.2	310.1	11.8
Power generation	22	276.7	266.4	10.2	393.5	363.7	30.2
Infrastructure	45	192.7	190.4	2.3	89.5	69.8	107.2
Manufacturing	163	98.9	23.6	75.4	51.0	52.6	3.0
Food & agriculture	60	36.3	31.5	4.8	9.6	4.3	3.6
Transportation services	39	29.3	28.7	0.6	94.4	5.3	1.9
Services	69	29.1	9.5	19.6	23.8	25.1	0.3
Retail	25	10.4	5.3	5.0	2.2	1.9	0.2
Apparel	3	1.0	0.3	0.6	0.6	0.7	0.0
Biotech & health care	11	0.7	0.5	0.3	0.5	0.5	0.2
Hospitality	3	0.2	0.0	0.2	0.1	0.6	0.0
Total	625	2 090.8	1 883.9	206.9	1 303.2	1 118.8	164.8

Source: CDP Questionnaire database (2023) & Authors' calculations.

Table 37: Quantile of minimum and maximum internal carbon prices by currency

Currency	#	1%	5%	10%	25%	α 50%	75%	90%	95%	99%
ALL	1 502	0.00	1.39	4.5	11.3	38	80	107	139	414
	1 481	0.00	5.13	9.0	22.5	65	107	171	268	860
BRL	58	0.00	0.19	2.1	4.3	8	13	37	96	140
	58	1.89	2.33	4.3	7.6	13	39	106	177	260
CAD	32	0.00	1.63	8.6	14.8	37	48	74	94	242
	32	0.00	5.65	11.3	36.9	85	125	135	181	242
EUR	331	0.00	5.35	8.0	32.1	75	96	107	161	604
	328	3.24	8.27	17.3	58.9	95	107	203	322	890
GBP	66	0.06	4.65	7.2	21.7	60	97	120	123	152
	65	1.22	7.18	12.1	32.9	79	116	181	377	754
INR	49	0.00	0.00	6.8	11.0	18	30	49	80	101
	46	0.00	4.02	9.7	11.3	19	40	86	109	157
JPY	276	0.00	1.73	7.6	22.9	53	76	114	153	356
	274	0.00	3.67	14.1	38.1	76	109	153	224	763
KRW	105	4.78	8.09	8.9	12.7	19	28	72	84	119
	104	8.93	13.00	15.9	18.9	25	66	104	191	1 248
TRY	40	0.00	2.31	4.5	9.4	42	77	115	128	160
	40	0.00	2.82	7.4	16.1	85	107	214	290	420
TWD	61	0.00	0.79	3.3	9.8	36	52	143	192	535
	63	1.06	6.85	9.8	48.8	52	121	538	810	1 932
USD	311	0.00	0.00	2.1	9.7	27	62	100	146	400
	302	0.00	4.89	9.7	20.0	55	109	237	282	928

Source: CDP Questionnaire database (2023) & Authors' calculations.

Table 38: Annual growth rate of the median internal carbon price by industry (in %)

Industry	2018	2019	2020	2021	2022	2017-2018
Apparel	−24.5	23.5	2.9	−41.1	−8.1	−12.3
Biotech & health care	3.7	−15.7	51.9	−22.5	31.3	6.2
Food & agriculture	−14.2	40.6	28.2	21.2	10.2	15.6
Fossil fuels	−10.0	22.8	13.4	59.5	41.6	23.2
Hospitality	−28.3	−6.3	−3.0	162.8	−42.2	−0.2
Infrastructure	16.7	5.6	24.1	16.1	35.8	19.2
Manufacturing	33.4	6.9	30.6	37.9	18.6	25.0
Materials	26.9	11.4	30.6	36.3	26.3	26.0
Power generation	−4.1	20.6	−6.7	22.0	−3.7	4.9
Retail	−3.9	4.8	21.9	2.2	35.2	11.1
Services	7.4	0.5	28.9	16.1	41.6	18.0
Transportation services	33.9	8.7	39.9	34.8	73.0	36.6
Total	14.1	13.6	20.0	31.9	30.4	21.7

Source: CDP Questionnaire database (2018-2023) & Authors' calculations.

B Technical appendix

B.1 External carbon pricing stringency score

To track the policies to which the various firms in our sample are subject, we constructed a national performance index. Unlike more complex and general indices, such as the OECD's environmental policy stringency index (Kruse *et al.*, 2022), our metric relies exclusively on market-based instruments. What defines the stringency of an external carbon pricing instrument depends on the coverage, price, and maturity of the system. We expect policy stringency to increase with the level of these dimensions. Using data from the World Bank (2023), we combine these three characteristics and separate the analysis between ETS and carbon taxes. Our dataset consists of 125 regulations, including 70 ETS and 55 carbon taxes that are either implemented, under development, or under consideration. In the first step, for each instrument type (*i.e.*, ETS or carbon tax), raw data are aggregated at the country level to estimate the cumulative share of nationwide GHG emissions covered, the average carbon price[25], and the average time since implementation. The latter is used to determine the maturity of the scheme, which is intended to reflect the current stage of policy development.

Let X_1, X_2 and X_3 be the three features considered here (coverage, price and time). For each country c, and for each instrument type k (ETS and carbon tax), we perform a z-score normalization of the raw data:

$$z_{c,j}^{(k)} = \frac{\left(x_{c,j}^{(k)} - \hat{\mu}_j^{(k)}\right)}{\hat{\sigma}_j^{(k)}}$$

where x is the individual observation, $\hat{\mu}$ and $\hat{\sigma}$ are the empirical mean and standard deviation of the data. Two intermediate scores are then obtained by combining the z-scores:

$$\boldsymbol{\mathcal{S}}_c^{(k)} = \sum_{j=1}^{3} w_j z_{c,j}^{(k)}$$

where w_j is the weight associated with the j^{th} feature. Assuming $\sum_{j=1}^{3} w_j = 1$, we assign a weight of 40% to coverage, 40% to price, and 20% to time. The final environmental policy stringency (EPS) score is the average of the two intermediate (ETS and carbon tax) scores for the country:

$$\boldsymbol{\mathcal{S}}_c^{\text{EPS}} = \frac{\boldsymbol{\mathcal{S}}_c^{\text{ETS}} + \boldsymbol{\mathcal{S}}_c^{\text{CT}}}{2}$$

We get an index of national carbon pricing stringency ranging from -0.83 (Israel) to $+1.31$ (Sweden). EPS scores are given in Table 39.

[25] Explicit prices are preferred to implicit prices because revenues are missing for many instruments.

Table 39: Environmental policy stringency (EPS) score

Country	$\mathcal{S}_c^{\mathrm{ETS}}$	$\mathcal{S}_c^{\mathrm{CT}}$	$\mathcal{S}_c^{\mathrm{EPS}}$
Sweden	1.06	1.55	1.31
Austria	1.25		1.25
Belgium	1.12		1.12
Italy	1.11		1.11
Norway	1.04	1.09	1.07
Finland	1.14	0.94	1.04
Germany	0.92		0.92
Ireland	1.21	0.34	0.77
Switzerland	0.34	1.10	0.72
Luxembourg	0.75	0.67	0.71
Denmark	0.93	0.45	0.69
Uruguay		0.58	0.58
France	0.83	0.26	0.55
Portugal	1.00	0.07	0.53
Netherlands	1.25	−0.27	0.49
Singapore		0.37	0.37
Spain	1.04	−0.63	0.20
Canada	0.25	0.07	0.16
United Kingdom	0.36	−0.11	0.13
New Zealand	0.92	−0.85	0.03
Hong Kong	0.02		0.02
Japan	−0.58	0.48	−0.05
United States	−0.59	−0.83	−0.71
Australia	−0.82		−0.82
Israel		−0.83	−0.83

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