Renewable and Sustainable Energy Reviews 168 (2022) 112780

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

External carbon costs and internal carbon pricing

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ARTICLE INFO

Keywords:
Internal carbon pricing
External carbon costs
Climate policy stringency
Country characteristics
Firm characteristics

ABSTRACT

The use of internal carbon prices (ICPs) is a practice by which companies voluntarily attach a hypothetical cost to their carbon emissions to help prioritize low-carbon investment projects. We find that ICP use is driven by external carbon constraints and by firms' exposure to formal carbon pricing systems, next to various firm and society characteristics. The size of the gap between countries' actual and intended emissions alone, without a translation into stringent climate policies, does not play a role. These findings inform policymakers and investors about when and why firms account for future carbon constraints internally. A key societal risk is that corporate investments are not sufficiently directed at a future low-carbon economy. Stringent climate policies that provide predictable pathways appear to help firms mitigate the misalignment of their investments by using ICPs and thereby contribute to a less erratic and less expensive transition of the energy system.

1. Introduction

National and international commitments of governments to curb carbon emissions[1] require stringent policy action to increase the cost of emitting carbon [1], through explicit carbon taxes and/or other policies such as sector- or technology-specific restrictions, standards, or subsidies. These policies are meant to influence the decisions of economic agents, firms and consumers alike. Because of their substantial carbon emissions and contribution to climate change, in particular multinational firms must play a vital role in achieving global emission-reduction targets [1–3]. Carbon pricing is an important means to arrive at decarbonizing the energy system [1]. It influences the price of fossil energy sources compared to the price of renewable ones. Therefore, studying carbon pricing is highly relevant for the deployment and scaling up of renewable and sustainable energy [2]. In particular, it is important to study how firms' expectations of future carbon constraints affect their investment practices. When firms are concerned about carbon risk, this might trigger decarbonization investments. By bringing forward their investment in low-carbon activities, firms can anticipate expected future carbon constraints and become less sensitive to uncertain and volatile future carbon costs [4,5]. However, when climate policy is uncertain and does not create predictable carbon constraints, it will be difficult to align corporate investment with a low-carbon economy and the need of advancing renewable and sustainable energy. A misalignment of investments can have substantial macroeconomic repercussions in the form of stranded assets [6,7], resulting in an erratic and expensive transition of the energy system. Uncertainty about future carbon costs may also act as a break on corporate investment, especially when investment projects exhibit irreversibility and optionality features [8–10].

The aim of this study is to understand the problems of international companies in achieving their emission targets in order to contribute to a low-carbon future. The study investigates what drives firms' low-carbon investment decisions. The main interest lies in whether and to what extent these decisions are driven by carbon constraints imposed by current and expected future climate policies as well as carbon cost uncertainty. This is done by investigating firms' use of internal carbon prices (ICPs), as these can be regarded as a key means to guide their investments in relation to climate change [11–13]. This study tests whether the adoption of ICPs and/or ICP levels reflect the anticipation of future constraints of firms' carbon emissions.

ICPs are a financial tool through which firms attach a virtual price to a ton of CO_2e emitted by their activities [11]. [13] provide an encompassing review of the literature regarding the impacts and barriers to the implementation of ICP. They provide an inventory regarding the motives for organizations to use ICPs, which will be included in this paper's

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[1] 'Carbon' is used to refer to the combination of the most important greenhouse gases (GHGs), represented in metric tons of CO_2-equivalents (CO_2e) based on global warming potential factors, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

https://doi.org/10.1016/j.rser.2022.112780
Received 15 April 2022; Received in revised form 7 June 2022; Accepted 7 July 2022
Available online 27 August 2022
1364-0321/

List of abbreviations, units, nomenclature

AME	Average Marginal Effect
C3I	Climate Change Cooperation Index
CAT	Climate Action Tracker
CCPI	Climate Change Performance Index
CDP	Carbon Disclosure Project
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
EPU	Economic Policy Uncertainty
ETS	Emission Trading System
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse gas
ICB	Industry Classification Benchmark
IPCC	Intergovernmental Panel on Climate Change
ln	natural logarithm
LPM	Linear Probability Model
LULUCF	Land Use, Land-Use Change and Forestry
Max	maximum
Min	minimum
Mt	megatonne
NDC	Nationally Determined Contribution
PIK	Potsdam Institute for Climate Impact Research
Prob	probability
R&D	Research and Development
StDev	standard deviation
t	tonne
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USD	US dollar
VIF	Variance Inflation Factor

models. Furthermore [14], examine firms' carbon-reduction targets and call for a further analysis on concrete firm carbon-reduction activities and their determinants. This paper complements this literature and studies how the concrete practices of ICP adoption and ICP level-setting are affected by climate policy, carbon cost uncertainty, and a range of other society- and firm-level factors. Although current climate policies worldwide do not tend to give strong incentives to reduce carbon emissions, a growing number of, typically large, international firms adopts an ICP (see Fig. 1).

ICPs are not new, but wide public disclosure started in 2014 [11,13,15,16]. At year-end 2017, the most recent moment for which public information on the ICP practices exists, about 1400 firms—including more than 100 Fortune Global 500 firms representing annual revenues of about USD 7 trillion—adopted an ICP or planned to adopt one within the next two years.

Disclosed ICP levels exceeded 'external' carbon prices under carbon pricing systems and legislations: ICPs are on average USD 34/tCO_2e and half of them lie above USD 23/tCO_2e (Fig. 2). By comparison, the carbon price in the EU Emission Trading System (EU ETS), for instance, was well below 10 euros/tCO_2e during the sample period. This suggests the ICP levels might reflect a concern about future carbon regulation. Case study evidence [11] suggests that some firms treat the ICP as an expected (shadow) price. This is in line with [14], who find that the emission-reduction targets set by firms are typically more stringent than current national climate targets. The ICPs also diverge substantially across firms, ranging from USD 1–204, with a standard deviation of USD 37. This divergence occurs even within the same geographical region, sector, and year (Fig. 3). The wide variation in the internally applied carbon costs might reflect an underlying uncertainty regarding the future 'external' carbon costs.

This paper empirically investigates to what extent firms' use of ICPs, as well as the level of these internal prices, is driven by expected carbon constraints and uncertainty about future carbon costs. The analysis features three innovations to understand the role of climate policies in firms' ICP practices. First, it uses several direct measures of climate policy stringency, measuring firms' exposure to formal carbon pricing systems and the carbon constraints implied by current policies and future additional policies required to meet policy targets. Second, it examines the role of uncertainty about future carbon costs in ICP practices. This analysis uses the dispersion in ICPs within a focal firm's peer group as a measure of carbon price uncertainty. Third, the effect from other potential drivers is isolated by accounting for a comprehensive set of country-, institutional-, and firm-level factors and applying thorough robustness analyses.

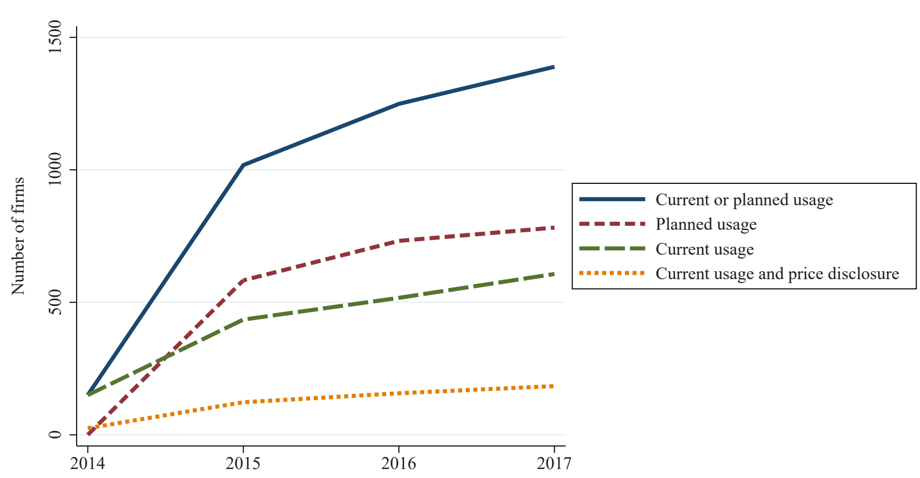

Fig. 1. Internal Carbon Price (ICP) usage, by year.
Source: CDP, authors' calculations.

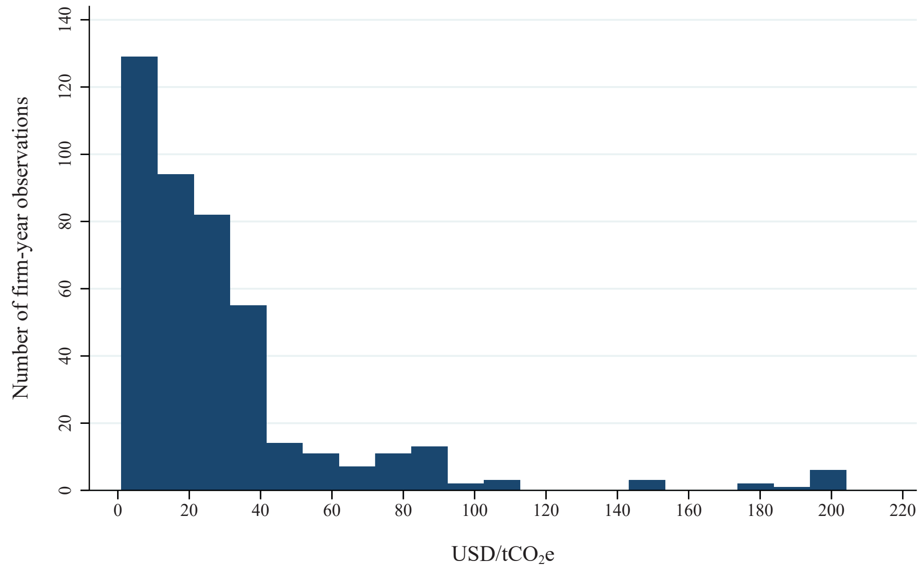

Fig. 2. Frequency distribution of Internal Carbon Price (ICP) levels.
Source: CDP, authors' calculations.

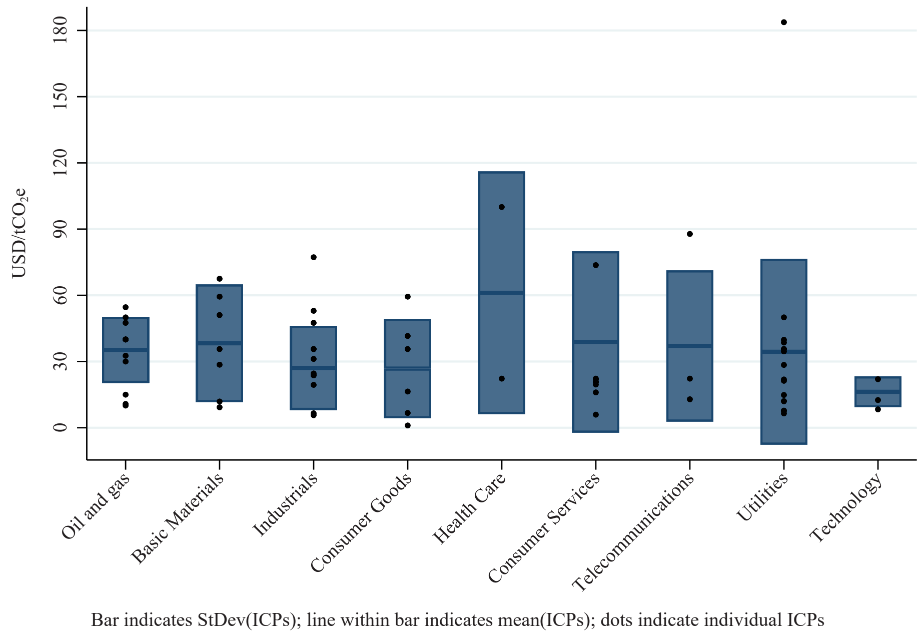

Fig. 3. Distribution of Internal Carbon Price (ICP) levels, by region and ICB Industry (example for EU in 2017).
Source: CDP, authors' calculations.

2. Materials and methods

This section provides the hypotheses, the way these are tested, and the contribution to the academic debate. Furthermore, it details the research design and data sample. A flowchart (Fig. 4) is included to help readers understand how the study tries to address the questions in the paper.

2.1. Hypothesis

The global climate goals require a significant intensification of carbon constraints worldwide in the short term [1,17]. This poses a real financial risk. Firms might anticipate this risk by using ICPs or raising the level of their ICPs [5]. Following [4], we hypothesize that an important economic driver for the ICP use is strategic risk management as this provides the firms with a concrete instrument to bring forward investments in low-carbon activities in anticipation of the future intensified carbon constraints and to become less sensitive to uncertainty about the future costs of emitting carbon. Specifically, we hypothesize that the (expected future) stringency of climate policies is positively related to ICP uptake and ICP levels. We further hypothesize that the ICP use is more prevalent and the ICP levels are higher in firms for which the future carbon costs are a highly salient issue and which face substantial investor attention regarding their environmental performance, such as high-emitting, capital-intensive firms [4,13,18].

Another aim of the study is to find out how uncertainty about future carbon costs affects firms' low-carbon investment decisions. The issue of carbon cost uncertainty has grown as a key concern to several corporate

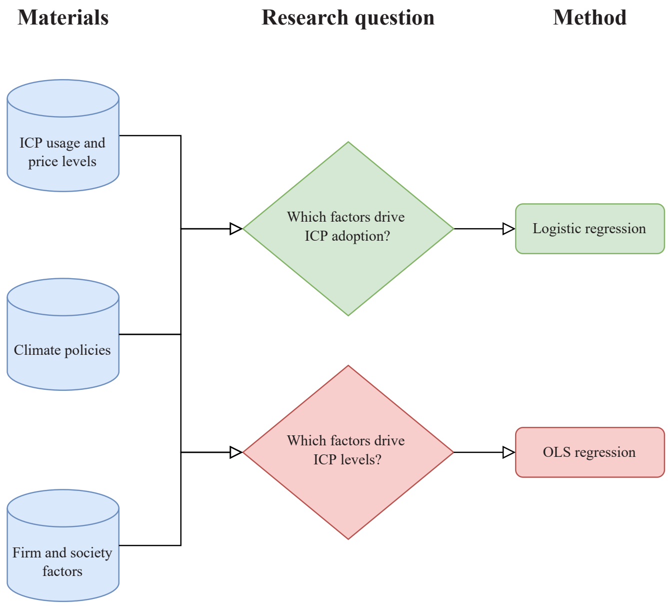

Fig. 4. Flowchart of materials, research questions, and methods.

stakeholders, especially investors, which demand better measurement and management of carbon risks [3,12,18–20]. The hypothesis is that a higher level of uncertainty about the future carbon costs is linked to lower ICP uptake and lower ICP levels, given that ICPs are a tool to *bring forward* low-carbon investment projects: the dominant real-options perspective theorizes that – because of irreversibility and optionality features of investment projects – firms will postpone investments until uncertainty is sufficiently reduced [8–10]. The current ICP practices and the high ICP levels observed in Figs. 2 and 3 support the motivation for this hypothesis. Furthermore, it is tested whether information on the expected tightness of climate policy affects the use and level of ICPs. An aversion to long-term climate risk and extreme carbon cost scenarios might induce firms to speed up their low-carbon investment projects [21–23]. Such investments might also be driven by a fear of strategic disadvantages from late investment in decarbonization [24,25].

2.2. Contribution

The analysis features three innovations to understand the role of climate policies in firms' ICP practices [13]. First, it uses three different direct measures of climate policy stringency, measuring the carbon constraints implied by (1) current policies, (2) future additional policies required to meet policy targets, and (3) carbon pricing systems. This contributes to the literature, which by and large has relied on generic and indirect policy indicators. Second, it examines the role of uncertainty about future carbon costs in ICP practices. To this end, the study employs the dispersion in ICPs within a focal firm's peer group as a measure of carbon price uncertainty. Third, the effect from other potential drivers is isolated by accounting for a comprehensive set of country-, institutional-, and firm-level factors and by applying thorough robustness analyses (included in the Online Supplementary materials). This also helps reveal which external settings and firm characteristics are conducive to low-carbon investment practices like those through ICP practices. These innovations specifically contribute to two recent studies exploring possible drivers of ICP levels [26,27]. [26] investigate how ICP levels relate to the presence of national carbon pricing systems in the country of firms' headquarters and to some specific firm characteristics (firm size, profitability, and the percentage of independent or female directors). [27] additionally account for country and sector effects. This paper adds to these specific studies in the following ways: (1) it considers both ICP levels and ICP adoption, (2) it tests for the role of climate policy stringency using direct policy measures, (3) it tests for the role of current carbon pricing systems by measuring exposure to such systems based on firms' operations rather than their headquarters, (4) it investigates the role of uncertainty about future carbon costs, and (5) it isolates policy factors from other potential drivers by accounting for a comprehensive set of factors and by validating the results using a range of robustness analyses.

2.3. Research design

The analysis starts with the univariate comparisons of mean micro- and macro-level characteristics of ICP adopters and non-adopters. Then, it uses the following multivariate logit model to explain the likelihood of ICP adoption by the expected carbon costs and carbon cost uncertainty:

$$\ln\left[\frac{\text{prob}(ICP\ adoption_{it})}{1-\text{prob}(ICP\ adoption_{it})}\right] = \alpha + \beta\, Stringency_{ct} + \gamma\, Explicit\ price_{it} + \delta\, Uncertainty_{rst} + \varepsilon' X_{it} + \Lambda + \varepsilon_{it} \tag{1}$$

In equation (1), $ICP\ adoption_{it}$ is a binary variable which equals 1 if firm i in year t uses an ICP, and 0 otherwise. $Stringency_{ct}$ is one of the two measures of expected carbon costs at a country-year level, described below. $Explicit\ price_{it}$ is a firm-specific binary indicator that equals 1 if the firm has operations under the EU ETS or another carbon pricing system (i.e., an ETS or carbon tax), and 0 otherwise. $Uncertainty_{rst}$ is a proxy for carbon cost uncertainty faced by firms within the same geographical region r (based on the seven continents), sector s (based on 10 industries), and year t, described below. X_{it} is a vector of time-varying firm and society characteristics. Λ is a set of fixed effects, which includes year-fixed effects in our baseline specification to control for time-trends in ICP adoption and ICP levels. Further analyses also control for sector and region effects. Standard errors are clustered at the country level to account for dependence in our primary variable of interest, which is *Stringency*, and to be conservative in the interpretation of our estimates.[2] The magnitude of coefficient estimates is interpret with the help of the average marginal effect (AME), which shows the effect of a one-unit change in the variable of interest on the predicted probability of ICP adoption, keeping other predictors at their observed levels, averaged over all individuals.[3]

To examine the drivers of ICP levels, giving particular attention to the role of expected carbon costs and carbon cost uncertainty, the following model is used:

$$\ln(ICP\ level_{it}) = \alpha + \beta\, Stringency_{ct} + \gamma\, Explicit\ price_{it} + \delta\, Uncertainty_{rst} + \varepsilon' X_{it} + \Lambda + \varepsilon_{it} \tag{2}$$

In equation (2), the dependent variable, $\ln(ICP\ level_{it})$, is the natural logarithm of the ICP level in USD/tCO_2e being set by firm i in year t. The natural logarithm of the ICP level is used to be able to interpret the marginal effects of our covariates as approximate percentage changes in the ICP level. All other variables are the same as in equation (1).

[2] Descriptive statistics are in Table A.2. Due to the relatively small number of clusters (36 countries), it is verified that the results are robust to using bootstrapped standard errors following [28], as well as to firm-level clustering of standard errors (results are available upon request). Furthermore, multicollinearity might result in large standard errors. However, as the pairwise correlations are well below 0.8 (see Table A.3) and Variance Inflation Factors (VIFs) are below 3 for each covariate (results are available upon request), there is no concern regarding multicollinearity.

[3] The odds ratios of our results are presented in Table A.4. The odds ratios reflect how the likelihood of ICP adoption relative to non-adoption increases with a one-unit change in the variable of interest. For instance, the odds ratio of *Explicit price* implies that firms subject to an explicit carbon price are roughly 4 times more likely to use an ICP than firms not subject to an explicit carbon price. Table A.5 is a verification of the robustness of the results by estimating marginal effects using a linear probability model (LPM).

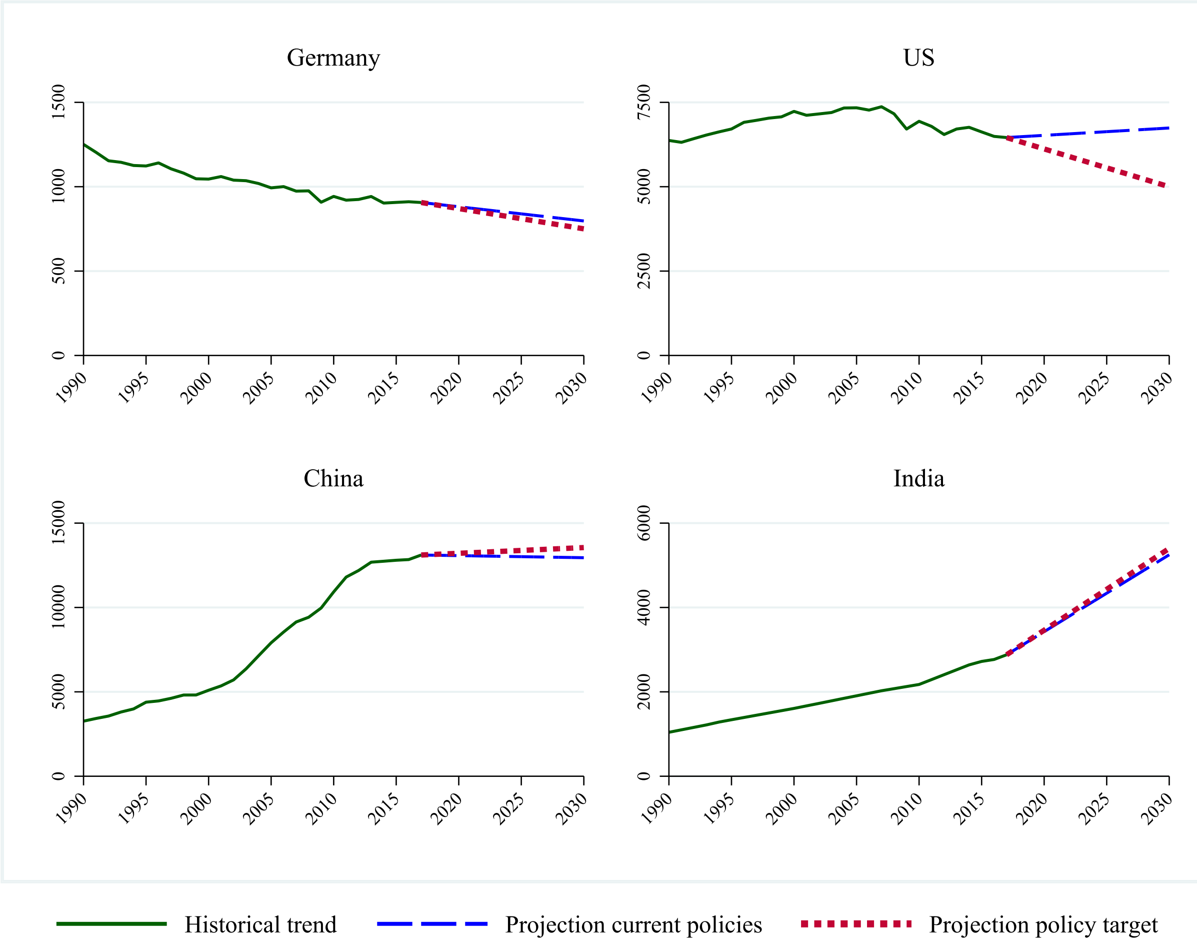

Fig. 5. Carbon emission pathways ($MtCO_2e$): Historical and projected emissions.
Source: CAT, authors' calculations.

A concern with equation (2) might be that ICP level disclosure is voluntary and non-random. A two-step Heckman procedure [29], however, indicates that the decision to report the use of ICPs and the ICP levels is not related to firm characteristics and there is no significant selection bias that could threaten the generalizability of the estimates (see Table A.6). Another issue could be the potential simultaneity bias occurring in the regression of ICP levels on *uncertainty,* which is based on ICP level dispersion. This can only be partially addressed (see Table A.7), and, therefore, the results regarding the hypothesis on carbon cost uncertainty are inconclusive.

2.3.1. *Stringency of carbon constraints*

Carbon constraints posed to firms' activity stem from a broad mixture of emission-reduction policies at the (supra-)national level, such as restrictions, standards, tax-credits, and subsidies, next to more direct carbon pricing systems. Surprisingly, despite ambitious global emission-reduction commitments [1] only about a fifth of global carbon emissions are covered by current (16%) or scheduled (7%) carbon pricing systems [33]. Therefore, a relevant measure for the expected carbon costs should not merely focus on current carbon pricing systems, but rather reflect the combined policy actions taken to constrain carbon emissions.

The policy stringency measures must also provide transparent and forward-looking indicators of the constraints on carbon emissions imposed by (supra-)national climate policies. Alternative proxies for climate policy stringency used in the literature include counts of climate laws in a country [30] and stringency indices, such as the Climate Change Cooperation Index (C3I) [31] and the Climate Change Performance Index (CCPI) [32]. However, the former is indirect and does not focus on imposed carbon constraints, while the latter assesses historical output and emissions trends in a broader range of environmental policy categories, and as such does not necessarily reflect the stringency of carbon constraints faced by firms going forward.[4] The aim of this study is to use measures that align much closer to economic theory and policymaking.

To this extent, the study departs from the policy assessments from Climate Action Tracker (CAT), which quantify countries' 2030 carbon emissions levels as implied by their implemented or enacted climate policies as well as the levels implied by countries' formal climate policy target. These emission projections have been used in highly regarded climate policy analyses, such as [17]. From the CAT projections, two measures of policy stringency at the country-year level are constructed. These measures reflect the rate at which carbon emissions are being reduced on average per year, expressed as a percentage relative to a common base year (2010). The intuition of the two measures is that the steeper the emission-reduction pathway implied by current or required future policy actions in a particular country, the more stringent will be the expected carbon constraints to firms in that country. This is illustrated with two figures. Fig. 5 shows the CAT emission data on which the measures are based for four selected countries, while Fig. 6 presents the

[4] CCPI has correlations of 0.02 with our measure of *current policy stringency*, −0.19 with our measure *stringency of required additional policies*, and 0.07 with the presence of a carbon pricing system. The C3I lacks availability for the sample period.

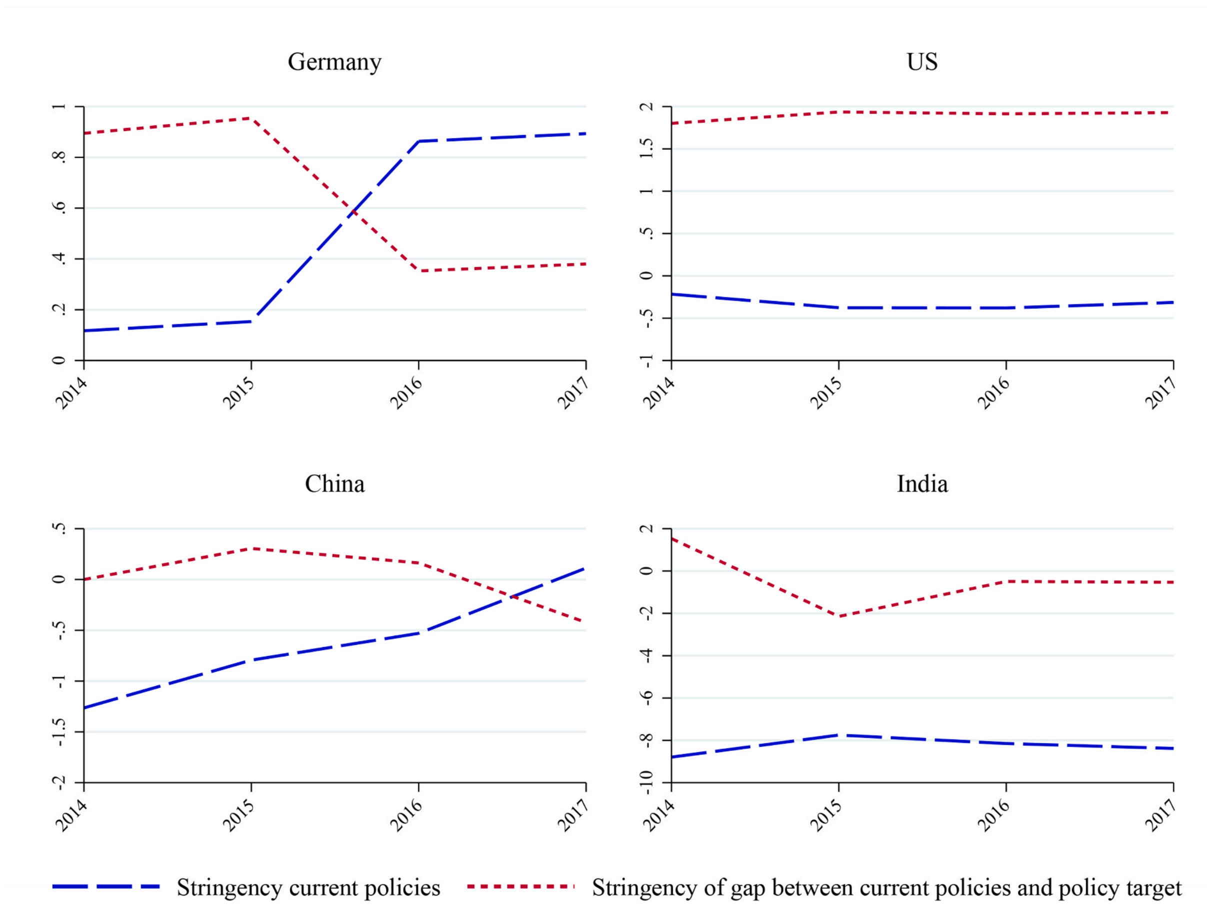

Fig. 6. Stringency measures: average annual reduction implied by current policies and the gap between current policies and formal policy target (as a percentage of the 2010 emission level).
Source: CAT, authors' calculations.

stringency measures. The first measure, *stringency current policies,* reflects the stringency of the carbon constraints expected from the countries' current climate policies. It is determined by the slope of the blue dashed line in Fig. 5. For the case of Germany in 2017, the projection by CAT is that, with current policies in place, carbon emissions will reach 797.2 $MtCO_2e$ in 2030. Given the current-year (2017) emission levels of 906.6 Mt, the current policy projection implies an average yearly reduction of 8.4 Mt per remaining year (109.5 Mt/(2030–2017)). The measure *stringency current policies* is defined as the yearly reduction (8.4 Mt) expressed as a percentage rate of emission levels in base year 2010, i.e. (8.4 Mt/942.5 Mt) * 100% = 0.9%. That is, Germany's current climate policies imply that the carbon emissions will be constrained until 2030 by on average 0.9 percentage points per year. This is shown by the solid blue dashed line in Fig. 5. Compared to most other jurisdictions, Germany's stringency is quite large and thus may imply relatively substantial future carbon costs to incentivize firms' emission reduction. In fact, the sample average stringency level is slightly negative, which means that the current policies imply a rise in carbon emissions until 2030; this is consistent with global emissions projections [17].

The second measure, *stringency required additional policies,* is more forward-looking as it reflects the stringency of future additional policies required to close the countries' *'emission gap'*, i.e. the gap between the emission level implied by the current policies and the emission level consistent with the countries' formal policy target. It is determined by the slope of the red dotted line in Fig. 5. For Germany in 2017, the formal policy target (unconditional NDC for 2030) was 750.6 Mt. The current policies were projected in 2017 to result in emissions of 797.2 Mt in 2030. Consequently, the emission gap of 46.6 Mt (797.2 Mt – 750.6 Mt) implies a yearly additional emission reduction effort of 3.6 Mt (46.6 Mt/(2030–2017)). The measure *stringency required additional policies* is defined as this yearly additional reduction (3.6 Mt) expressed as a percentage rate of emission levels in base year 2010, i.e. (3.6 Mt/942.5 Mt) * 100 = 0.4%. This is shown by the red dotted line in Fig. 6. The measure indicates by how much current climate policies would need to be intensified in order to achieve the formal policy target. The measure is relatively large for Germany compared to other jurisdictions, most notably China and India. This has to do with the fact that, as shown by Fig. 5, policy targets in China and India imply a further increase rather than a reduction of carbon emissions.

Note that the stringency measures exhibit variation *between countries*, due to the presence of national climate policies next to supranational policies, and *over time*, because of three underlying factors: (1) each year, climate policies may change and CAT correspondingly updates its current policies projection of the implied 2030 emission levels; (2) climate policy targets may change over time; and (3) each year going forward reveals new information about the realized emission levels and hence about the distance between the current emissions, the projected emissions, and the gap between projected and target emissions, which will alter the tightness of the expected future policies.

2.3.2. *Exposure to explicit carbon pricing systems*

This study uses a firm-specific binary indicator from the Carbon Disclosure Project (CDP), which captures firms' exposure to formal systems that put a price on carbon explicitly, namely an ETS or a (supra) national carbon tax. The measure equals 1 if the firm has operations under a formal carbon pricing system, such as the EU ETS, and 0 otherwise. This measure is more accurate than the commonly used measure based on World Bank data at the country level [33], which identifies firms' exposure to national carbon pricing policies based on the location of their headquarters [26,27]. In fact, this firm-specific measure has a weak pairwise correlation (0.18) with the country-level indicator.

2.3.3. Uncertainty about future carbon costs

The amount of dispersion in the price levels of internal carbon prices used by a group of peer firms can be viewed as a proxy for the uncertainty about future carbon costs by the amount of dispersion in the price levels of internal carbon prices used among peer firms. The ICPs are typically used as expected future costs of emitting carbon [11]. Hence, when ICPs of comparable firms are close to each other, future carbon cost estimates will closely align, revealing a relatively low level of uncertainty about future carbon cost levels. Conversely, if ICPs of comparable firms are strongly dissimilar, this reveals a relatively high level of uncertainty about future carbon costs. The dispersion is calculated as the standard deviation in ICP levels within a given sector, region, and year.[5] Naturally, the ICPs might also reflect different capital asset characteristics, such as investment horizon, which are primarily sector-related. Current carbon regulations are also, to a large extent, specific to sector and region. This motivates the inclusion of such factors in the regression. However, the main analysis shows that firm-level factors in general do not significantly predict ICP levels.

The use of dispersion-based measures of firm- or sector-level uncertainty is a well-established approach in the finance and accounting literature [34–36]. The proxy for carbon cost uncertainty is close to Refs. [37–39], who exploit the dispersion in survey respondents' expected sector-level demand growth and economic conditions to measure demand uncertainty. A strength of using dispersion-based measures is that they relate to specific economic variables (here: future carbon costs) and exposed agents (firms within a particular sector), representing a distribution around an expected or a consensus value. The common alternative policy uncertainty measures usually are more generic, e.g., indices based on uncertainty-related words counts in newspapers [40,41].

A limitation of the dispersion measure is that it assumes homogenous use of ICPs within the prespecified subgroups of firms as a future carbon cost expectation, whereas to date, little is known about the ICP level setting in practice [11]. Moreover, this measure might also capture forecaster (firm) attributes unrelated to their perceived uncertainty [35]. In robustness analyses, Tables A.11 and A.12, this is to some extent alleviated by calculating ICP dispersion only for firms in high-carbon sectors that use high ICPs, given that case study evidence suggests that the ICPs in such firms are most likely to function as expected future carbon cost estimates [11]. The robustness is also assessed by using the widely-employed Economic Policy Uncertainty (EPU) index [41] as an alternative uncertainty proxy (see Tables A.9 and A.10).

2.4. Identification of effects

To ensure that the estimated effects for expected carbon constraints and carbon cost uncertainty are not driven by general country-level, or institutional factors, a set of time-varying variables that capture heterogeneity at these levels is included. First, given the importance of a firm's legal and institutional environment for shaping a firm's orientation and performance towards addressing sustainability issues and in line with the literature [42,43], a set of dummies for *legal origin* from Ref. [44] is included. Additional controls are included for a country's economic development, which might influence the propensity for emission-reduction activity, using the natural logarithm of *GDP* per capita.

Next, a wide range of firm characteristics that might explain ICP adoption and price levels is explored. Due to the close relationship between ICP practices and corporate social responsibility, the literature on corporate social responsibility determinants [43,45,46] is used for the selection and measurement of explanatory variables. As firms may use an ICP as an expectation of future carbon costs [11], a key determinant factor will be the length of firms' investment horizon, which relates to sector affiliation (e.g., compare investment projects in the technology sector and oil and gas sector), asset tangibility, and longevity of capital assets. Consequently, the model accounts for *sector affiliation* (ICB industries), *asset tangibility*, and *capital intensity*. Variable definitions are in Table A.1 in the appendix.

As ICP use may originate from firms' general environmental strategy or stakeholder pressures to improve environmental performance, rather than (merely) being a response to carbon constraints as such [4], it is important to account for firms' environmental performance (*environmental rating*) and *carbon emissions*. As larger firms are more visible and likely face larger stakeholder pressures to decarbonize their activities [4], *firm size* is included as well. Given the potential influence of institutional investors in driving corporate initiatives [43,46], the level of *institutional ownership* is included in the model measured by the percentage of common shares owned by pension funds or investment companies [20].

Additionally, there model controls for several factors that are known to relate to firm performance and environment-related practices such as ICP use. *Leverage* is accounted for because adopters and non-adopters might differ in their access to debt financing [47]. Relatedly, ICP use might be linked to firms' risk profile. In particular, low-risk firms may be more likely to adopt ICPs and to set premium ICP levels, so as to mitigate sensitivity to shocks in future carbon costs. Therefore, *systematic risk is* included in the model using a common specification [48], which captures the sensitivity to macroeconomic fluctuations. Adoption of environmental initiatives might further follow from (be endogenously determined with) the availability of resources in firms' pursuit to maximize profits and market value [49]. Hence, there are controls for *profitability* and value effects through *Tobin's Q*. Furthermore, there are controls for potential differences in investment opportunities among ICP adopters and non-adopters by including *cash flow* [50],[6] as well as for differences in liquidity using *stock liquidity* [51] and *working capital* [52].

To rule out the possibility that any remaining unobserved sector- or region-specific factors drive the estimates, sector- and/or region-fixed effects are added in a second specification (see also [14]). As the estimates showed to be very similar to the baseline estimates, the set of control variables in this baseline model (equation (1)) already seems sufficiently extensive to control for potential confounding factors.

2.5. Data

Data on ICP usage is collected from CDP reports for all available years, which is 2014–2017.[7] The ICP data is matched to firm-level data for all firms covered in the Thomson Reuters ASSET4 dataset (about 7900) using Bureau van Dijk Orbis, Bloomberg, and manual checking. Data on countries' historical and projected emissions per capita are

[5] In some instances, ICP dispersion is based on only few ICPs. Results remain qualitatively similar when (1) requiring at least two ICP level observations per region-sector-year to calculate ICP dispersion and (2) measuring dispersion in ICPs applied within a sector-year instead of region-sector-year (see Tables A.9 and A.10).

[6] Given that Research and Development (R&D) might be a driver of environmental practices, such as ICP use, a check regarding the robustness of the results to including R&D intensity (R&D expenses divided by total assets) seems warranted. There is no control for R&D intensity in the main regression specification, as this would reduce the sample by more than 50%. However, it appears that R&D intensity does not enter significantly in the regressions, and does not alter the main results (results are available upon request).

[7] https://www.cdp.net/en/reports/archive.

retrieved from Climate Action Tracker (CAT). CAT is a set of tools from Climate Analytics, NewClimate Institute, and the Potsdam Institute for Climate Impact Research (PIK), which evaluates and monitors climate policy actions of 59 countries, covering about 80% of global GHG emissions.[8] CAT uses country-level United Nations Framework Convention on Climate Change (UNFCCC) data on GHG emissions excluding emissions from Land Use, Land-Use Change and Forestry (LULUCF), and population projections are based on the medium-fertility scenario of the United Nations [53]. When multiple ICP levels are being disclosed (e.g., to reflect operations in different jurisdictions), the mean level is taken as a best estimate of the ICP level used within the entire firm.[9] To ensure that extreme price observations[10] do not heavily influence either the measure of ICP dispersion or the estimates of equation (2), ICP level data are winsorized at the 1st/99th percentile. The final sample used in the regressions consists of 12274 firm-year observations (of which 1441 (12%) are cases (i.e., $ICP\ adoption_{it} = 1$ in equation (1)), corresponding to 62 cases per predictor) from 3725 firms, spanning 36 countries over the years 2014–2017.

3. Results

3.1. ICP adopters vs. non-adopters

ICP adopters and non-adopters are found to differ in several respects, as shown in Table 1: the ICP adopters are more likely to be in countries with more ambitious climate policies and in sectors with greater uncertainty about future carbon costs. More than half of the adopters have operations subject to an explicit carbon price (through an ETS or carbon tax), while for non-adopters this is only 1 out of 17. Current explicit carbon pricing regulation might thus be closely linked to internal pricing practices. Furthermore, ICP adoption is more prevalent in civil law than common law countries. This indicates that country-level institutions shape firms' decisions to use ICPs. The ICP adopters are also larger, both in terms of assets and emissions (11 vs. 2 $MtCO_2e$), have better environmental performance ratings (84 vs. 52 out of 100), have more tangible assets, and are subject to lower systematic risk. This suggests that ICP adoption aligns with firms' broader environmental management strategy, but multivariate analyses should verify this result. The positive relationship between environmental ratings and carbon emissions has been observed in prior literature as well [52,54].

Table 1
Adopters vs. non-adopters: Univariate comparisons of means (2014–2017).

Internal carbon price (ICP)	(1) Adopters (N = 1441)	(2) Non-adopters (N = 10833)	(3) T-statistic (unequal variances assumed)
External carbon costs			
Stringency policies (%)	−0.22	−0.57	−6.36***
Stringency policy target (%)	0.83	0.73	−1.54
Stringency required additional policies (%)	1.11	1.34	6.39***
Carbon cost uncertainty ($, N = 7853)	26.45	23.50	−3.65***
Explicit carbon price (% yes)	50.52	6.01	−33.29***
Country and institutional setting			
Income ($)	10.49	10.54	2.25**
Legal origin (% common law)	50.94	65.85	10.70***
Firm characteristics			
High-carbon sector (% yes)	65.65	48.12	−13.08***
Size	16.48	15.00	−38.93***
Leverage (%)	29.75	26.56	−5.85***
Systematic risk	0.86	0.89	2.88***
Profitability (%)	5.10	4.72	−1.34
Asset tangibility (%)	41.01	30.58	−15.64***
Capital intensity (%)	5.64	4.93	−6.19***
Tobin's Q	2.06	2.44	7.28***
Cash flow (%)	269.78	87.06	−19.38***
Stock liquidity	0.46	0.67	14.00***
Working capital (%)	144.33	74.57	−7.55***
Institutional ownership (%)	4.78	7.99	15.14***
Environmental rating (0–100)	83.99	52.45	−61.08***
Carbon emissions ($MtCO_2e$)	11.22	2.36	−13.18***

All variables are defined in Table A.1.

3.2. Determinants of ICP adoption and ICP levels

Tables 2 and 3 show the multivariate results on the determinants of ICP adoption and ICP levels respectively (see equations (1) and (2) respectively). For this study, the specific interest lies in whether ICP practices are driven by external carbon constraints and/or carbon cost uncertainty.

The multivariate results (Table 2) of equation (1) show that ICP adoption is significantly driven by the tightness of climate policies towards the year 2030. In countries with a 1 percentage point higher annual CO_2e emission reduction rate, the probability of ICP adoption is on average 1 percentage point higher. Furthermore, firms that are currently subject to an explicit carbon pricing system have a 10–13 percentage points higher predicted probability of ICP adoption.[11] No significant effects were found for the size of countries' *'emission gap'*, which indicates how much climate policies need to be intensified in order to meet their formal climate policy targets. There is no significant effect of uncertainty about future carbon costs on ICP use. The univariate association of ICP use with higher uncertainty (Table 1) seem to be predominantly attributable to firm and, societal characteristics (Table 2). More specifically, the probability of ICP adoption increases by 1–1.2 percentage points for each 1% increase in firm size, by 0.2–0.3 percentage point for every 1 point increase in the firm's environmental rating, and by 0.6–0.7 percentage point for every 1% increase in it's absolute CO_2e emission levels. These results suggest that ICP adoption strongly relates to visibility and stakeholder pressures [4] rather than to carbon cost uncertainty. In line with the literature, societal factors such as legal origin are found to be relevant [43]. These results contribute to prior studies on the drivers of firms' environmental performance [43,45], as the relevance of each driver can be directly interpreted in terms of predicted probabilities of ICP use (Table 2) and in terms of the actual carbon price levels set by firms.

In sum, with ambitious climate policies and regulatory instruments such as carbon pricing in place, expectations about future carbon constraints seem to become more salient for firms' decision-making, as indicated by the higher (predicted) uptake of ICP practices. The estimation results for regression model (1) suggest that it is the explicit carbon pricing systems and the expectations of the tightness of climate policies, and not so much the uncertainty about future carbon costs, that get firms to prioritize low-carbon investments through their ICP practices.

Table 3 informs about the determining factors of ICP *levels*, in particular, the influence of the stringency of and the uncertainty about

[8] A distinct advantage of the CAT-based stringency measures is their good coverage, due to which there is a minimal mismatch between the CAT and ICP datasets. Specifically, over 96% of the ICP observations could be included in the analysis.

[9] The results are not affected when excluding firms that disclose multiple prices (results available upon request).

[10] Three firms disclose ICP levels in the range USD 350–900/tCO_2e. The results uphold when using the raw ICP level data and when winsorizing at the 5th/95th percentile (result available upon request).

[11] One might ask why firms already facing an 'external' carbon price would still apply carbon prices internally. There appear to be three possible explanations: (1) firms use ICPs to anticipate rising external prices; (2) firms use different ICP systems that help them achieve organizational emission-reduction targets; or (3) firms used ICPs before the external carbon price was introduced.

Table 2
Determinants of internal carbon price (ICP) adoption (logistic regression; 2014–2017).

	(1)	(2)	(3)	(4)
External carbon costs				
Stringency policies	0.009**		0.009**	
	(0.004)		(0.004)	
Stringency required additional policies		0.005		0.009*
		(0.005)		(0.005)
Explicit carbon price	0.100***	0.101***	0.125***	0.123***
	(0.015)	(0.015)	(0.020)	(0.020)
Carbon cost uncertainty			0.000	0.000
			(0.000)	(0.000)
Country and institutional setting				
Income	−0.009	0.008	0.019	0.034***
	(0.014)	(0.010)	(0.015)	(0.011)
Legal origin (base = common law)				
French civil law	−0.024	−0.002	−0.065***	−0.050***
	(0.022)	(0.020)	(0.014)	(0.014)
German civil law	−0.052***	−0.031**	−0.075***	−0.060***
	(0.015)	(0.015)	(0.020)	(0.022)
Scandinavian civil law	−0.055***	−0.042**	−0.090***	−0.083***
	(0.018)	(0.018)	(0.014)	(0.014)
Firm characteristics				
High-carbon sector	0.017***	0.017***		
	(0.006)	(0.006)		
Size	0.010***	0.011***	0.012**	0.012**
	(0.003)	(0.004)	(0.005)	(0.005)
Leverage	−0.000	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Systematic risk	−0.005	0.001	0.012	0.016
	(0.012)	(0.012)	(0.015)	(0.015)
Profitability	0.001**	0.001*	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Asset tangibility	−0.001	−0.001	−0.000	−0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Capital intensity	0.001***	0.001***	0.001**	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)
Tobin's Q	0.004	0.005*	0.009***	0.009***
	(0.002)	(0.002)	(0.003)	(0.003)
Cash flow	−0.000	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Stock liquidity	−0.034***	−0.035***	−0.031***	−0.030***
	(0.008)	(0.009)	(0.007)	(0.007)
Working capital	−0.000	−0.000	0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Institutional ownership	−0.000	−0.000	−0.001	−0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Environmental rating	0.002***	0.002***	0.003***	0.003***
	(0.000)	(0.000)	(0.000)	(0.000)
Carbon emissions	0.006**	0.006**	0.007	0.007
	(0.003)	(0.003)	(0.004)	(0.004)
Year fixed effects	Yes	Yes	Yes	Yes
Sector fixed effects	No	No	Yes	Yes
Region fixed effects	No	No	Yes	Yes
N	12274	12274	7853	7853
(Pseudo) R^2	0.332	0.330	0.353	0.352

The estimated equation is Eq. (1). Robust standard errors clustered at the country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10. All variables are defined in Table A.1.

Table 3
Determinants of internal carbon price (ICP) levels (OLS regression; 2014–2017).

	(1)	(2)	(3)	(4)
External carbon costs				
Stringency policies	0.029		0.010	
	(0.079)		(0.043)	
Stringency required additional policies		−0.153**		0.012
		(0.064)		(0.091)
Explicit carbon price	0.201	0.170	0.026	0.026
	(0.164)	(0.159)	(0.118)	(0.115)
Carbon cost uncertainty			0.014***	0.014***
			(0.002)	(0.003)
Country and institutional setting				
Income	0.508**	0.511***	0.463**	0.484***
	(0.182)	(0.116)	(0.186)	(0.122)
Legal origin (base = common law)				
French civil law	−0.212	−0.304	−0.167	−0.143
	(0.312)	(0.189)	(0.215)	(0.168)
German civil law	−0.170	−0.278	−1.090***	−1.074***
	(0.388)	(0.333)	(0.316)	(0.290)
Scandinavian civil law	0.214	0.283	0.255	0.243
	(0.436)	(0.401)	(0.267)	(0.307)
Firm characteristics				
High-carbon sector	0.310	0.318		
	(0.227)	(0.227)		
Size	0.145	0.165	0.223**	0.224**
	(0.130)	(0.132)	(0.104)	(0.106)
Leverage	−0.000	−0.001	0.004	0.004
	(0.006)	(0.006)	(0.005)	(0.005)
Systematic risk	0.014	−0.028	−0.222	−0.207
	(0.311)	(0.304)	(0.211)	(0.190)
Profitability	0.002	0.002	0.006	0.006
	(0.007)	(0.007)	(0.007)	(0.007)
Asset tangibility	0.002	0.002	0.003	0.003
	(0.006)	(0.006)	(0.005)	(0.005)
Capital intensity	0.008	0.012	−0.001	−0.001
	(0.027)	(0.026)	(0.022)	(0.022)
Tobin's Q	0.038	0.028	−0.062	−0.060
	(0.058)	(0.060)	(0.059)	(0.058)
Cash flow	−0.000	−0.001	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Stock liquidity	−0.354	−0.251	−0.101	−0.101
	(0.237)	(0.252)	(0.224)	(0.221)
Working capital	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Institutional ownership	0.017	0.016	0.019**	0.019*
	(0.011)	(0.011)	(0.009)	(0.010)
Environmental rating	0.012**	0.013**	0.012*	0.012
	(0.005)	(0.005)	(0.007)	(0.007)
Carbon emissions	−0.042*	−0.042*	−0.017	−0.017
	(0.024)	(0.024)	(0.038)	(0.036)
Year fixed effects	Yes	Yes	Yes	Yes
Sector fixed effects	No	No	Yes	Yes
Region fixed effects	No	No	Yes	Yes
N	359	359	343	343
Adj. R^2	0.257	0.274	0.472	0.472

The estimated equation is Eq. (2). Robust standard errors clustered at the country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.10. All variables are defined in Table A.1.

carbon constraints. It shows that the ICP levels are positively associated with the stringency of expected carbon constraints, but the associations are statistically insignificant. These results remain qualitatively the same when performing additional robustness analyses in which the analysis is restricted to high-carbon sectors and ICP levels that plausibly have been used as expected future prices (shadow prices) (Tables A.11 and A.12). Firm characteristics typically do not significantly predict ICP levels. Qualitatively, however, ICP levels do seem to be positively influenced by, amongst others, firms' exposure to explicit carbon pricing systems and firms' environmental rating.

To rule out alternative explanations of these findings, there is a series of robustness analyses, next to the comprehensive model employed in the main analysis (equations (1) and (2)). The robustness is verified against potential endogeneity issues (Tables A.6 and A.7) and alternative specifications of the ICP adoption variable and uncertainty variables (Tables A.8–A.10). In addition, there is evidence that climate policy factors have more pronounced effects in high-carbon sectors, for which future carbon costs are a highly salient issue (Tables A.11 and A.12).

4. Conclusion

This paper analyzes to what extent firms' investment practices are affected by the carbon constraints resulting from the current and expected future climate policies. It does so by investigating international firms' use of internal carbon prices (ICPs), as these are a key means to guide firms' investments in relation to climate change [11]. The use of ICPs is a voluntary practice through which firms attach a hypothetical price to their carbon emissions [13]. Such a cost can be incorporated in firms' capital budgeting decisions to prioritize low-carbon investments. The central question of this study is whether ICP adoption and ICP levels reflect the anticipation of future constraints imposed on firms' carbon emissions. To answer this question, several direct measures of climate policy stringency are used, the role of uncertainty about future carbon costs is examined, and the effect from a wide range of other potential drivers is isolated.

It finds that both the carbon constraints stemming from countries' climate policies and firms' exposure to explicit carbon pricing systems positively influence the likelihood of ICP adoption: in countries with 1 percentage point higher decarbonization rates implied by climate policies, the probability of ICP adoption is on average 1 percentage points higher. Exposure to explicit carbon pricing systems increases the probability of ICP use by 10–13 percentage points. There is no significant impact of the stringency of countries' future policies that is required to meet formal emission targets (the *'emission gap'*) nor of firms' revealed uncertainty about future carbon costs. ICP use is strongly and positively related to several firm characteristics, including size, environmental performance, and carbon emissions. No significant effect could be identified for policy-related factors of ICP *levels*.

As such, this study provides empirical evidence that corporate actions based on internal carbon prices (which may exceed explicit 'external' carbon prices) are related to expectations regarding future carbon constraints. Especially ambitious climate policies and explicit carbon pricing systems drive ICP practices, while less concrete factors like countries' '*emission gap*' seem to play no significant role. ICP practices furthermore seem to be driven by the salience of future carbon costs, as shown by the higher prevalence of ICPs in larger, high-emitting, and capital intensive firms. The results suggest that firms indeed use ICPs with the aim to bring forward low-carbon investments in anticipation of future carbon cost scenarios. In particular, this analysis establishes that propensities for low-carbon investment are highest when there are relatively stringent and tangible carbon cost signals.

The analysis features three innovations to understand the role of climate policies in firms' ICP practices [13,26,27]. First, it uses three different direct measures of climate policy stringency, measuring the carbon constraints implied by a) current policies, b) future additional policies required to meet policy targets, and c) carbon pricing systems. This contributes to the literature, which mainly relies on generic and indirect indicators. Second, it examines the role of uncertainty about future carbon costs in ICP practices by employing the dispersion in ICPs within a focal firm's peer group as a measure of carbon price uncertainty. Third, the effect from other potential drivers is isolated by accounting for a comprehensive set of country-, institutional-, and firm-level factors and by validating the results using a range of robustness analyses.

A limitation of the study is that it abstracts from the possibility of misreporting or greenwashing regarding disclosed use and levels of ICPs. Still, information about ICPs is open to investor scrutiny: one may verify the consistency between disclosed ICPs and strategic and operational decisions [14] and misreporting of this type of environment-related information likely comes with considerable reputational costs [55]. Another limitation is the identification of the actual carbon costs to which firms' production activities are subject. Future studies are necessary using more accurate data on production sites and individual exposures to climate policy measures in different countries. This calls for more extensive disclosure about the use, level, and practical implementation of ICPs. It may be expected that this information will become available as firms increasingly have to comply with more stringent environmental reporting obligations.

A policy implication is that stringent climate policies and explicit carbon pricing systems help provide predictable pathways to induce investments into low-carbon technologies. Adequate pricing of carbon emissions is important not only to address climate externalities but also to facilitate the anticipation of future carbon cost scenarios by firms and investors. Given that four-fifths of global carbon emissions carry no explicit price [33] and the global average explicit price being below 3 USD/tCO_2e in 2020 [56], it will be difficult for firms to align investments with a low-carbon economy. Stringent and tangible climate policies may help mitigate misalignment of investments and the resulting macroeconomic repercussions [6,7], and as such contribute to a less erratic and less expensive transition of the energy system.

For future research, it is important to expand the data and analysis. The results of this study can be verified using a larger sample when more information about ICP practices and price levels becomes available. In addition, more thorough assessments of the costs that international firms bear because of climate policies will be highly valuable to better understand the behavior of firms in relation to current and expected future climate policies. This requires granular data on production sites as well as the net climate policy costs across countries, sectors, and over time. When more firms adopt ICPs and disclose these, the results of the current study regarding their usage and the internal carbon price levels in relation to climate policy can be verified.

Author contributions

All authors contributed to the study design and writing of the manuscript. A. constructed the dataset and performed the data analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data are used under commercial license and therefore cannot be shared without the permission of the data providers (Refinitiv, Bureau van Dijk, and Bloomberg). The replication code can be shared.

Acknowledgements

We want to thank the editor and three anonymous reviewers for Renewable & Sustainable Energy Reviews for their constructive comments and suggestions. We gratefully acknowledge Carbon Disclosure Project (CDP) and Climate Action Tracker (CAT) for sharing the data. We also thank Tobias Böhmelt, Ursula Hagen, and Andrzej Ancygier for useful discussions on climate policy measures. We appreciate the valuable comments and suggestions received from Rob Alessie, Viola Angelini, Erik Ansink, Ambrogio Dalò, Steffen Eriksen, Carolyn Fischer, Daan Hulshof, Marcel Metzner, Dirk Schoenmaker, and seminar participants at Free University Amsterdam (February 2019), the University of Groningen (April 2019), the International Symposium on Environment and Energy Finance Issues (ISEFI) in Paris (May 2019), the Global Research Alliance for Sustainable Finance and Investment (GRASFI) conference in Oxford (September 2019), and (CPB Netherlands Bureau for Economic Policy Analysis) (September 2021). The usual disclaimer applies.

Appendix

Table A.1
Variable definitions.

Variable	Definition	Unit	Source
ICP use			
ICP adoption	A binary indicator which equals 1 if the firm uses an internal carbon price (ICP) and 0 otherwise.	Firm-year	CDP reports
ICP level	Internal carbon price (ICP) level used by the firm. When multiple ICPs are being used, the average ICP is taken as best estimate.	Firm-year	CDP reports
External carbon costs			
Stringency policies	[(*Projected emissions current policies* − *current emissions*)/(*Projection year* − *current year*)/*emissions in* 2010] *100%. *Projected emissions current policies* is defined as the CO_2e emissions implied by the country's policies in the current year, as projected by CAT.	Country-year	CAT
Stringency policy target	[(*Projected emissions policy target* − *current emissions*)/(*Projection year* − *current year*)/*emissions in* 2010] *100%. *Projected emissions policy target* is defined as the CO_2e emissions implied by the country's (I)NDC target in the current year, as projected by CAT. When multiple targets exist, we prioritize the most stringent target, target year 2030 above 2020, and unconditional above conditional targets.	Country-year	CAT
Stringency required additional policies	*Stringency policies* – *Stringency target*. It represents the yearly reduction of CO_2e emissions, expressed as a percentage of 2010 CO_2e levels, required to achieve the *projected emissions policy target*.	Country-year	CAT
External price	Binary indicator which equals 1 if the firm has activities that fall under the EU ETS or other carbon pricing scheme (ETS or carbon tax) and 0 otherwise.	Firm-year	CDP (Bloomberg)
Carbon cost uncertainty	Standard deviation of ICPs used within a sector from the same region and year.	Sector-region-year	CDP reports
Country and institutional factors			
Income	Natural logarithm of GDP per capita.	Country-year	World Bank
Legal origin	Set of dummies capturing legal origin (common law, French civil law, German civil law, and Scandinavian civil law).	Country	La Porta et al. (2008)
Firm characteristics			
High-carbon sector	ICB Industry codes 1 (Oil and gas), 1000 (Basic materials), 2000 (Industrials), and 7000 (Utilities).	Firm	Datastream
Size	Ln(total assets).	Firm-year	Datastream
Leverage	(Total debt/total assets) * 100%.	Firm-year	Datastream
Systematic risk	Market beta coefficient obtained from five-year rolling-window regressions of the firm's daily stock returns on the daily market return.	Firm-year	Datastream
Profitability	(Net income/total assets) * 100%.	Firm-year	Datastream
Asset tangibility	(Property, plant, and equipment (PPE)/total assets) * 100%.	Firm-year	Datastream
Capital intensity	(Capital expenditures/total assets) * 100%.	Firm-year	Datastream
Tobin's Q	(Common equity market value – common equity book value + total assets)/total assets.	Firm-year	Datastream
Cash flow	(Operating cash flow/fixed assets) * 100%.	Firm-year	Datastream
Stock liquidity	Average daily share turnover (daily shares traded divided by daily shares outstanding) over the previous year.	Firm-year	Datastream
Working capital	Net working capital: [(Current assets – current liabilities)/total assets] * 100%.	Firm-year	Datastream
Institutional ownership	Percentage of common shares owned by pension funds or investment companies.	Firm-year	Datastream
Environmental rating	Environmental performance rating from ASSET4.	Firm-year	Datastream
Carbon emissions	Ln(Scopes 1 and 2 greenhouse gas emissions in tCO_2e). Missing values are replaced by the estimated emissions from ASSET4 to allow for sufficient coverage.	Firm-year	Datastream

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2022.112780.

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