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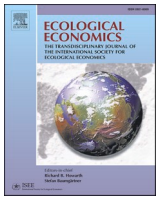

Analysis

A Global Survey of Scientific Consensus and Controversy on Instruments of Climate Policy

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ABSTRACT

There is continuing debate about which climate-policy instruments are most appropriate to reduce emissions. Undertaking a global survey among scientists who published on climate policy, we provide a systematic overview of (dis)agreements about six main types of policy instruments. The survey includes various fields across the social and natural sciences. The results show that, on average, all instruments are considered important, with direct regulation receiving the highest rating and adoption subsidies and cap-and-trade the lowest. The latter is surprising given the theoretical advantages and real-world success of the EU-ETS. Next, clustering scientific fields based on how important they consider the instruments, we determine five distinct groups, with (a) ecological economists and (b) mathematics/computer science being most dissimilar from other discipline clusters. We explain disagreement through assessing the relative importance assigned to policy criteria effectiveness, efficiency, equity and socio-political feasibility, as well as researchers' attitudes and background. Paying special attention to carbon pricing, motivated by its contested key role, we identify three respondent clusters, namely 'enthusiasts', 'undecided', and 'skeptics'. Examining various policy arguments, we find that agreeing that carbon pricing effectively limits energy/carbon rebound and has potential to be harmonized globally have the strongest association with giving importance to this policy.

1. Introduction

Both the theory and practice of climate policy show a large number of instruments. Despite decades of research, it is contested which of these are best capable of reaching emission reduction targets (e.g., Cullenward and Victor, 2020; Peñasco et al., 2021; van den Bergh et al., 2021). Most economists argue that carbon pricing should be a key instrument of climate policy (Baranzini et al., 2017; Cramton et al., 2017; Boyce, 2018). A large body of literature reports its impact on emissions and the economy, assessed theoretically (Aldy et al., 2010) as well as empirically (Martin et al., 2016; Best et al., 2020; Bayer and Aklin, 2020; van den Bergh and Savin, 2021). Less is known, though, what climate researchers from other scientific fields think of this instrument. In view of recent debates (Patt and Lilliestam, 2018; Tvinnereim and Mehling, 2018; Kirchner et al., 2019; Mildenberger and Stokes, 2020; Rosenbloom et al., 2020; Majkut, 2020; van den Bergh and Botzen, 2020), one gets the impression that carbon pricing is considered to be less important and more problematic in some than in other disciplines. Some economists even perceive their discipline as "a notable exception" when it comes to support given to carbon pricing (Blanchard and Tirole, 2022). The veracity of this claim is not established. Moreover, it is known from psychological research that perceptions of others' views can be inaccurate (Sokoloski et al., 2018; Schuldt et al., 2019; Goldberg et al., 2020; Drews et al., 2022).

In recent years, many studies have examined public opinion about carbon pricing (Carattini et al., 2018; Maestre-Andrés et al., 2019; Savin et al., 2020) and to a lesser extent other climate policy instruments (Drews and van den Bergh, 2016; Rhodes et al., 2017; Levi, 2021). However, there is little systematic evidence on what scientists from a wide range of disciplines think about carbon pricing within a broader

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mix of climate mitigation policies, or which alternatives they see as most adequate and viable. Understanding scientists' opinions about climate policy is important for at least two reasons. First, because it directly informs policymakers (Javeline and Shufeldt, 2014). Second, because public opinion about climate policy is partly shaped by information from scientists of different fields (Maliniak et al., 2020). In fact, citizens nowadays expect scientists to be outspoken on climate policies and communicate their findings to policymakers and journalists (Cologna et al., 2021). Universities even encourage such public engagement. This is partly because scientists tend to enjoy more public trust than other societal actors (Krause et al., 2019). Communicating expert consensus on policy has also been proposed as a way to garner more policy support from the general public (Lachapelle, 2017). It can further improve the process of synthesizing policy insights from research by the IPCC.

Surveying scientific opinion has already been used to assess the degree of consensus on basic tenets of climate science, both within the community of climate scientists (Cook et al., 2016) as well as in other disciplines (Carlton et al., 2015). With regard to climate policy and related issues, few studies have elicited opinions of scientists, which are largely limited to environmental economists (Howard and Sylvan, 2015). For example, one study finds that most economists agree that emission taxation or trading is a more efficient instrument than emission standards, but there is less agreement about how to use any revenues generated (Haab and Whitehead, 2017). A survey from 2005 shows that most US climate scientists tend to support the use of taxation and other forms of market incentives aimed at emission reduction (Rosenberg et al., 2010). There is however little evidence for how economists' opinions on climate policy compare with those of climate scientists or researchers from other disciplines.

To advance the debate on climate policy – and particularly on carbon pricing – we present here the findings of a new, global survey of 789 scientists who published on some aspects of climate change mitigation or policy, to elicit their views on criteria and instruments of climate policy. This has a broad coverage, including both economists and other (formal, social and natural) scientists. The aim of this study is threefold. First, we quantify the degree of (dis)agreement over climate policies between various research fields. This involves comparing how researchers judge the importance of six types of instruments in a policy mix. For this we use a comprehensive set of 15 research fields as well as employ cluster analysis to identify a reduced set of five field clusters. In addition to eliciting researchers' own judgments, we assess expectations about support from their colleagues' support for carbon pricing. A second aim is investigating factors explaining variation in policy views. Here we analyze how the importance assigned to instruments is associated with weights and ratings given to distinct criteria of policy performance, notably effectiveness, efficiency, equity and socio-political feasibility. Additional explanatory factors include researchers' general views (e.g., climate-change worry) and backgrounds (e.g., countries of residence, gender, research experience). A third and final aim is to examine arguments in favor and against carbon pricing. This involves assessing support for these including variation among disciplines, and identifying clusters of carbon-pricing 'enthusiasts', 'undecided' and 'skeptics'. These findings are also used to explain the importance assigned to other policy instruments.

The contribution of the present survey of scientists is to provide a detailed analysis of researchers' views about climate-policy instruments across a diversity of disciplines and epistemic communities – such as environmental and ecological economics, sustainability transition studies and geography, mathematics and computer science, sociology and psychology, political science and law, engineering and the natural sciences.

2. Methods

2.1. Survey Implementation and Sample

The sample frame of the survey was constructed as follows. We searched the academic database Web of Science for articles published between 2016 and 2021 (until June 22nd) using several relevant key terms ("carbon pric*" OR "carbon tax*" OR "cap-and-trade" OR "climate polic*" OR "mitigation of climate change" OR "climate change mitigation"). This search resulted in 10,822 documents and 18,417 email addresses. After removing duplicates (due to authors appearing in multiple articles), we remained with 15,070 unique email addresses.

The survey was programmed in the survey tool Cmix by Dynata. It was pretested with about 25 researchers from different fields and revised based on their feedback. Final data collection ran from mid-September to end of December 2021. An initial email invitation including a link to the survey was followed by two reminder emails in subsequent weeks (see Appendix C for precise wordings). The survey resulted in a final sample of 789 completed responses.[1] The median survey completion time was 21 min. Fig. A1 in the Appendix shows the country of residence and origin of the survey respondents, demonstrating that countries like China, Germany, the UK and the US are expectedly well-represented, while many respondents are from a variety of other countries from distinct continents. Furthermore, we know that 70% of our sample are male scientists and on average respondents of our survey have 18.5 years of experience in research (33% of the sample having less or equal to 10 years, and 32% over 20 years). Finally, a majority of our participants come from environmental economics (21%), natural science (14%), political science and engineering (each 11%) and sustainability transition (10%) which arguably reflect main scientific fields currently studying climate policy.

2.2. Survey Questions

The survey questions were formulated to address the three research aims outlined in Section 1. Following an introductory page, a request for consent, and two questions eliciting respondents' self-reported research field and topics, the participants were exposed to the three main parts of the survey. The first and major block of survey questions relates to instruments of climate policy, and weights and ratings of policy criteria. A first set of questions asked respondents how they generally judge the importance of four different types of policy criteria when evaluating instruments, namely effectiveness, efficiency, equity and feasibility. The importance of each criterion was rated on a five-point scale (from 1 = "unimportant" to 5 = "extremely important"). Next, respondents were asked to rate the six instruments of climate policy in terms of their performance on each of the four mentioned criteria, using a three-point scale (1 = "low", 2 = "moderate", 3 = "high"). These six instrument types were chosen to be direct regulation, carbon taxation, cap-and-trade, adoption subsidies, innovation support, and information provision, motivated by prior classifications (e.g., van den Bergh et al., 2021). After rating instruments on the criteria, respondents were asked to judge

[1] The relatively low response rate of 5.2% warrants clarification. Three considerations are relevant. First, about 400 email invitations bounced back, i.e., they could not be delivered (e.g. due to invalid email addresses). Second, a considerable number of emails most likely ended up in spam filters of researchers' email accounts. Third, while 3422 people accessed the survey, most of these dropped out early on. The reason is that such a large pool of people will have a varying degree of interest in the survey's objectives, which affects motivation to finish a survey (Steinbrecher et al., 2015). The high rate of dropout may also be influenced by the relatively long survey times (Galesic, 2006). In spite of these comments, our response rate is comparable to other surveys of scientists with a relatively wide sample frame (e.g., Aranzales et al., 2021).

the importance of each instrument in a climate-policy mix of a country (again on a 5-point scale of importance). Responses to this question are used as the main outcome variable in the statistical analysis.

The survey then moved from questions about a variety of instruments to the specific role of carbon pricing. To this end, respondents were presented with ten Likert-style statements related to carbon pricing (e.g., "Carbon pricing has little impact on the speed of low-carbon innovation"). These statements were partly inspired by a recent opinion exchange between Rosenbloom et al. (2020) and van den Bergh and Botzen (2020). We aimed to strike a balance between statements that can be interpreted to express favorable and critical judgments about carbon pricing. Responses were given on a five-point scale from "strongly disagree" to "strongly agree". To better understand the distribution of views about carbon pricing in different fields, we also asked respondents to estimate the percentage of researchers in their respective field of study who consider carbon pricing (in the form of a tax or cap-and-trade system) as a very or extremely important component of a country's policy mix. This was done to test the accuracy of researchers' expectations of support for carbon pricing, namely by comparing with actual estimates of support within the sample. It should be noted that in all our questions about carbon pricing (and other policies) we wanted to obtain responses relating to the essence of the policies, independent of their level of stringency. This is consistent with other opinion studies (e.g. Kyselá et al., 2019). A recent study by Drupp et al. (2022) provides a complementary assessment of expert views with a focuses on carbon pricing rates. Furthermore, this part of the survey included three open-ended questions about carbon pricing, which due to space constraints are not analyzed in the present study.

Following the inquiries about climate policy, respondents were asked four questions capturing more general climate/environmental attitudes. One of these asked how worried they were about climate change and its societal consequences (from 1 = "not at all worried" to 9 = "extremely worried"). Three questions elicited views on economic growth (e.g., "Economic growth is necessary to finance environmental protection"). Responses to these questions are used to segment respondents into one of three growth-vs-environment positions previously identified in survey-based research (Savin et al., 2021). Finally, participants were asked several questions on their research and personal background, namely their years of research experience, gender, country of origin and residence, and political orientation (measured on a scale from 1 = left to 11 = right). Almost all questions had a "Don't know" response option as well as an open-response field to provide additional comments. The full questionnaire, including precise question wordings and response formats, can be found in Appendix B.

2.3. Grouping of Respondents' Fields of Research

When asked to report their own research field, most participants selected one of the 12 predefined fields (e.g. environmental economics, political science; see the first survey question in Appendix B). However, about 140 respondents did not select one of these but instead "other", followed by entering their own description of a research field. This resulted in a very large number of fields. Using respondents' self-defined field, as well as their self-defined research topics (question 2), we reduced this number by categorizing fields in the following way. First, some respondents were moved to the predefined categories when this was deemed appropriate. For example, several researchers indicated "public policy" as their field, which is typically considered a subfield of political science. Those indicating environmental science or ecology were added to the category of natural sciences. For other respondents, we created several new categories. The largest is what we call "other environmental social science" ($n = 43$), which includes researchers who did not clearly identify themselves with a predefined social-science discipline and instead stated another field (e.g., "philosophy"). Two additional categories formed on the basis of these responses are industrial ecology and agriculture/forestry. Table A1 in Appendix A provides summary statistics for the research fields and other characteristics of the respondents.

2.4. Data Analysis

To formally test whether respondents rated importance of an instrument in a policy mix is significantly higher than of another instrument (Fig. 1), we employ a pairwise Mann–Whitney test that compares responses from the same individuals for stochastic dominance (see Fig. A2). For testing statistical differences between disciplines, we used Kruskal–Wallis rank-sum test with Bonferroni correction (see Fig. A3).

We next classified the fifteen disciplines in our sample into distinct groups based on how they evaluated the importance of the six policy instruments. For this purpose, we used hierarchical cluster analysis. This involved estimating Euclidian distances between the 15 disciplines based on the means of rated importance of the six instruments and identifying five clusters from the resulting dendrogram (Fig. 2). We chose hierarchical clustering over other approaches as the number of disciplines is small which allows for easily observing differences between the disciplines in a dendrogram.

In contrast, when it comes to classifying all individual researchers based on their responses to (i) the ten Likert statements regarding carbon pricing and (ii) the three statements on the debate between economic growth and environmental protection (Savin et al., 2021) we used the Latent Class Analysis (LCA). Among the advantages of LCA is the provision of a range of fitness indices (like information criteria) to determine the optimal number of clusters and a proven ability to recover true group structures where alternative clustering methods fail (Bacher et al., 2004; Drews et al., 2019). A considerable number of "Don't know" responses reduced our sample to 571 observations. Information criteria suggested three clusters (see Fig. A13 in the Appendix A): CP skeptics (211respondents), CP undecided (159) and CP enthusiasts (201). Similarly, we applied LCA to classify researchers based on their views on the debate between economic growth and environmental protection using their responses on three statements on a 5-point Likert scale. As here only 20 researchers answered "Don't know" to at least one out of the three statements, the sample was reduced from 789 to 769 observations. As a result, we find that three clusters is the best option based on both corrected Akaike and Bayesian information criteria (Fig. A14). The number of researchers in these clusters – called Green growth, Agrowth and Degrowth – are 208, 343 and 218, respectively.

In order to test how the importance of an instrument of climate policy is affected by respondents' experience, discipline, views on the importance of different policy criteria, position in the growth-vs-environment debate and other factors, we ran ordered logit regressions (Tables 1 and 2). This choice is motivated by our dependent variables taking the form of discrete ordered choices varying from "unimportant" to "extremely important". We further used this technique to examine associations of carbon-pricing statements with importance given to policy instruments.

3. Results

3.1. Rated Importance of Instrument Types in Policy Mix

We start by analyzing the rated importance of six types of policy instruments across research fields. As shown in the top panel of Fig. 1, every instrument type is judged on average as at least "important" (i.e. value 3 on the Likert scale) by almost every research field. Direct regulation is the instrument with the highest assessed importance, closely followed by innovation support, carbon taxation and information provision. Less important are considered adoption subsidies and cap-and-trade (Fig. A2 in the Appendix provides further information about the statistical significance of differences between the importance of the instruments). It is worth noting that carbon taxation is particularly preferred over cap-and-trade in Europe and the North America, while in

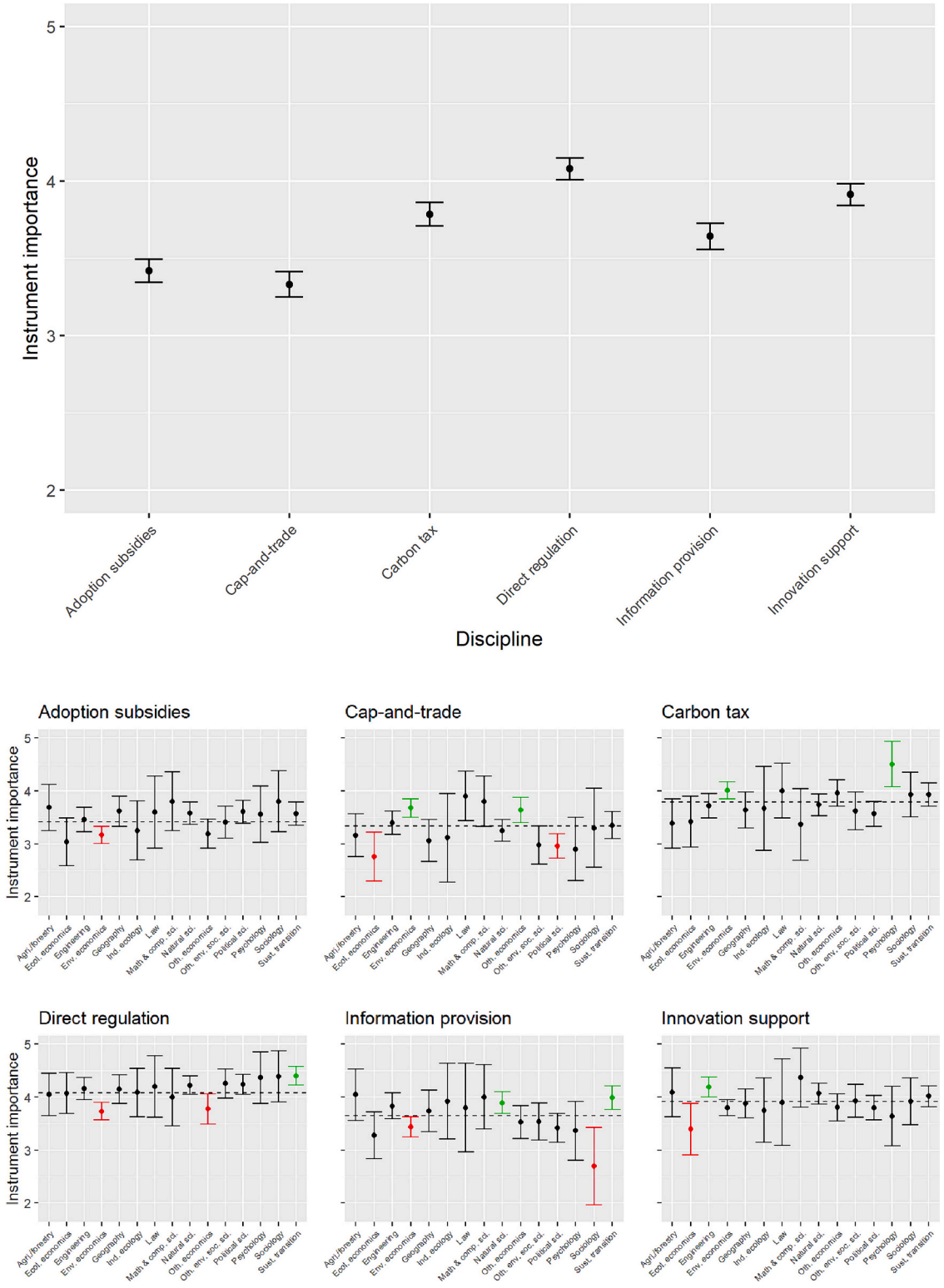

Fig. 1. Rated importance of instruments. Aggregate results shown in the upper panel, and by discipline in the lower panel. The scale on the Y-axis ranges from 1 = rated as unimportant to 5 = rated as extremely important. Data points represent mean values and error bars ±2s.e. The dashed lines in the lower-panel graphs indicate average importance; green and red colors mean that the score for a discipline is significantly above or below the average among all disciplines, respectively. For more statistical details, see Fig. A4 in the Appendix. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

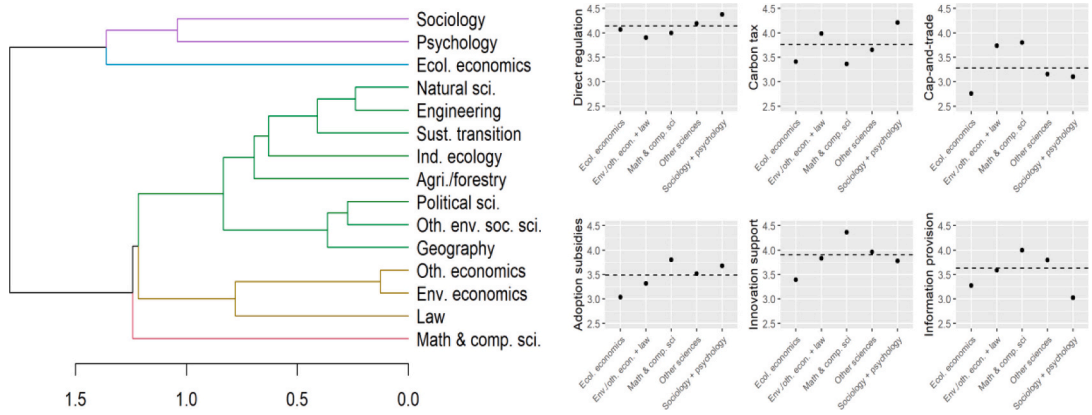

Fig. 2. The left panel represents a dendrogram suggesting clusters of disciplines. Main clusters are indicated by distinct colors; the x-axis indicates the Euclidian distance between disciplines based on the importance assigned to the six instrument types. The right panel shows the assessed policy importance averaged over all disciplines in each cluster; the dashed line marks the average over all clusters.

Table 1
Ordered logit regression of rated importance of instruments on policy criteria and additional factors.

Variable	Direct regulation	Carbon tax	Cap-and-trade	Adoption subsidies	Innovation support	Information provision
General importance of policy criteria						
Effectiveness	1.61** (1.2–2.1)	1.35** (1.1–1.7)	1.23 (0.0–1.6)	1.17 (0.9–1.5)	1.24 (0.9–1.6)	1.10 (0.9–1.4)
Efficiency	0.91 (0.7–1.1)	1.21 (1.0–1.5)	1.30* (1.1–1.6)	0.96 (0.8–1.2)	1.17 (1.0–1.4)	1.20 (1.0–1.5)
Equity	1.29* (1.0–1.6)	1.16 0.9–1.5)	1.12 (0.9–1.4)	1.37** (1.1–1.7)	1.17 (0.9–1.5)	1.41** (1.1–1.8)
Feasibility	1.19 (1.0–1.5)	0.96 (0.8–1.2)	1.01 (0.8–1.2)	1.21 (1.0–1.5)	1.25* (1.0–1.5)	1.39** (1.1–1.7)
Rating of instruments on policy criteria						
Effectiveness	4.31** (2.9–6.4)	3.89** (2.8–5.5)	5.57** (3.8–8.1)	4.18** (3.0–5.9)	2.39** (1.7–3.4)	2.63** (1.9–3.6)
Efficiency	2.06** (1.6–2.7)	2.09** 1.5–2.9)	2.04** (1.5–2.9)	1.97** (1.4–2.7)	2.47** 1.8–3.5)	1.51** (1.1–2.0)
Equity	1.27 (1.0–1.7)	1.25 (1.0–1.6)	1.39* (1.0–1.9)	1.53** (1.2–2.0)	1.91** (1.4–2.5)	1.88** (1.4–2.5)
Feasibility	1.01 (0.8–1.4)	1.51** (1.2–2.0)	1.41* (1.1–1.9)	1.52** (1.1–2.1)	1.68** (1.2–2.3)	1.32 (1.0–1.8)
Researcher views						
Expected importance of carbon pricing	1.00 (1.0–1.0)	1.01** (1.0–1.0)	1.01 (1.0–1.0)	1.00 1.0–1.0)	0.99 (1.0–1.0)	0.99 (1.0–1.0)
Climate-change worry	1.22** (1.1–1.4)	1.16* (1.0–1.3)	1.13 (1.0–1.3)	1.21* (1.0–1.4)	1.05 (0.9–1.2)	1.11 (1.0–1.3)
Political orientation	0.87* (0.8–1.0)	0.90* (0.8–1.0)	1.01 (0.9–1.1)	1.00 (0.9–1.1)	1.02 (0.9–1.2)	0.95 (0.8–1.1)
Agrowth	0.95 (0.6–1.5)	0.95 (0.6–1.5)	1.02 (0.6–1.6)	0.79 (0.5–1.3)	1.00 (0.6–1.6)	1.07 (0.7–1.7)
Degrowth	1.04 (0.6–1.9)	0.77 (0.4–1.4)	0.66 (0.4–1.2)	0.62 (0.3–1.1)	0.86 (0.5–1.6)	0.95 (0.5–1.7)
Researcher characteristics						
Research experience	0.99 (1.0–1.0)	1.00 (1.0–1.0)	1.00 (1.0–1.0)	0.98* (1.0–1.0)	0.98* (1.0–1.0)	1.00 (1.0–1.0)
Gender	0.85 (0.6–1.3)	1.37 (0.9–2.0)	1.46 (1.0–2.2)	1.28 (0.9–1.9)	1.07 (0.7–1.6)	0.61* (0.4–0.9)
Ecological economics	2.15 (0.8–6.0)	0.53 (0.2–1.3)	0.61 (0.2–1.5)	0.49 (0.2–1.3)	0.37 (0.1–1.1)	0.59 (0.2–1.4)
Env./oth. Econ. + law	0.60* (0.4–0.9)	1.20 (0.8–1.9)	1.01 (0.6–1.6)	0.93 (0.6–1.5)	0.94 (0.6–1.5)	0.90 (0.6–1.4)
Sociology + psychology	0.83 (0.3–2.4)	1.50 (0.6–4.3)	0.88 (0.3–2.5)	1.22 (0.5–3.3)	0.43 0.2–1.1)	0.27** (0.1–0.7)
Asia	4.09* (1.1–14.7)	1.04 (0.3–3.7)	1.26 (0.3–4.7)	1.05 (0.3–3.8)	1.72 (0.4–6.3)	1.00 (0.2–3.9)
Europe	2.52 (0.7–8.7)	1.85 (0.5–6.4)	1.93 (0.5–7.0)	1.38 (0.4–4.9)	2.46 (0.6–8.8)	0.70 (0.2–2.6)
North America	3.66 (1.0–13.5)	1.42 (0.4–5.2)	0.86 (0.2–3.3)	1.78 (0.4–6.7)	3.48 (0.8–13.6)	0.48 (0.1–2.0)
Oceania	3.07 (0.7–13.1)	0.85 (0.2–3.5)	1.97 (0.5–8.4)	0.92 (0.2–3.9)	3.16 (0.7–13.8)	0.73 (0.1–3.2)
South America	8.26* (1.5–48.7)	1.47 (0.3–8.3)	1.76 (0.3–10.2)	2.23 (0.4–12.2)	11.13* (1.7–84.1)	2.84 (0.5–17.5)
Nagelkerke pseudo R^2	0.43	0.45	0.54	0.45	0.44	0.47

Note: Coefficients obtained with ordered logistic regression indicate odds ratios with 2.5–97.5% confidence intervals expressed within brackets. Asterisks ** and * denote 1% and 5% statistical significance, respectively. Agrowth and Degrowth are categorical variables with Green Growth as the reference group. The largest cluster of disciplines (including, among others, geography and natural sciences) serves as the reference group. We also ran regressions including interactions between general policy criteria and criteria-based policy ratings, but these specifications gave rise to multicollinearity.

other regions the difference is very small (Fig. A3). This might be judged as surprising for scientists from Europe given the success of the European Union's emissions trading system (EU-ETS). Next, the lower panel of Fig. 1 shows that most variation across research fields is found for information provision and cap-and-trade, while most consensus holds for direct regulation and innovation support (see for more statistical details Fig. A3 and Table A2). In addition to quantitative ratings, some respondents provided qualitative comments. For example, some suggested that interpretations of information provision vary, ranging from simple information campaigns to influence isolated consumer decisions to education aimed at changing lifestyles.

Environmental and other economics are the only two fields showing significantly less enthusiasm about direct regulation, while researchers of sustainability transitions are more positive about this instrument than the average of the sample. Environmental economists also express more favorable views about both types of carbon pricing (Fig. A4 in the Appendix provides results of statistical tests). In addition, ecological economics is one of the fields that assigns the least importance to several instruments, namely adoption subsidies, cap-and-trade, and innovation support while their support for direct regulation is similar to the average

Table 2
Ordered logit regression of rated importance of policies on carbon-pricing beliefs.

Variable	Direct regulation	Carbon tax	Cap-and-trade	Adoption subsidies	Innovation support	Information provision
Cost internalization	0.87 (0.7–1.0)	1.13 (1.0–1.3)	1.30** (1.1–1.5)	0.98 (0.8–1.2)	1.07 (0.9–1.3)	1.04 (0.9–1.2)
Innovation speed	0.98 (0.8–1.1)	0.84* (0.7–1.0)	0.97 (0.8–1.1)	0.94 (0.8–1.1)	1.08 (0.9–1.3)	1.07 (0.9–1.2)
Rebound	1.11 (1.0–1.3)	1.61** (1.4–1.9)	1.31** (1.1–1.5)	1.03 (0.9–1.2)	0.99 (0.9–1.1)	1.09 (0.9–1.3)
Small change	1.19* (1.0–1.4)	0.88 (0.8–1.0)	0.94 (0.8–1.1)	1.13 (1.0–1.3)	1.10 (1.0–1.3)	1.01 (0.9–1.2)
Decentralized policy	0.89 (0.8–1.0)	0.93 (0.8–1.1)	1.18* (1.0–1.4)	0.81** (0.7–0.9)	0.99 (0.9–1.1)	0.90 (0.8–1.0)
Contextual policy	1.46** (1.2–1.7)	0.91 (0.8–1.1)	0.96 (0.8–1.1)	1.35** (1.2–1.6)	1.29** (1.1–1.5)	1.49** (1.3–1.7)
Price sensitivity	1.04 (0.9–1.2)	1.19 (1.0–1.4)	0.92 (0.8–1.1)	0.87 (0.7–1.0)	1.00 (0.8–1.2)	0.97 (0.8–1.2)
Policy harmonization	1.03 (0.9–1.2)	1.38** (1.2–1.6)	1.27** (1.1–1.5)	1.13 (1.0–1.3)	1.10 (1.0–1.3)	1.26** (1.1–1.5)
Bounded rationality	1.04 (0.9–1.2)	1.01 (0.9–1.2)	1.11 (0.9–1.3)	1.20* (1.0–1.4)	1.03 (0.9–1.2)	1.18* (1.0–1.4)
Public revenues	1.06 (0.9–1.2)	1.14 (1.0–1.3)	1.00 (0.9–1.2)	1.12 (1.0–1.3)	1.02 (0.9–1.2)	1.16 (1.0–1.4)
Nagelkerke pseudo R^2	0.13	0.30	0.17	0.12	0.06	0.13

Note: Coefficients indicate odds ratios with 2.5–97.5% confidence intervals expressed within brackets. Asterisks ** and * denote 1% and 5% statistical significance, respectively.

of the sample; sociologists show a marked dislike of information provision; and psychologists are most enthusiastic about carbon taxation. Figs. A5–8 in Appendix A depict rated effectiveness, efficiency, equity, and feasibility for each instrument type. In addition, Figs. A9–12 show how each discipline judges the importance (i.e. weight) of the four policy criteria, with differences being most pronounced for efficiency and feasibility (Table A2 provides coefficients of variation calculated for the estimated means over all disciplines). A common theme among the few respondents who provided comments was that ratings of policy criteria, and ultimately importance, depend in part on the particular conditions of a country.

To better understand differences and similarities between disciplines, we conduct a hierarchical cluster analysis of the mean rated importance of the six instruments among all disciplines. Results shown in the left panel of Fig. 2 suggest five main clusters, namely: (i) sociology and psychology; (ii) ecological economics; (iii) a heterogeneous group consisting of various social and natural sciences; (iv) environmental and other economics, and law; and (v) mathematics and computer sciences. The right panel of Fig. 2 shows that the five clusters are rather similar with regard to judging direct regulation but differ markedly regarding cap-and-trade and information provision.

We also examine how researchers think colleagues in their field view climate policy. The reason is that social influence of peers may play a role in the formation of researcher's opinions. Indeed, science is a social undertaking. We focus this part of the study on carbon pricing, given controversy about its key role in climate policy in academic debate. Here, we provide a graphical analysis of researchers' expectations about disciplinary support for carbon pricing. Fig. 3 shows the results, with black dots and error bars displaying responses to a question on expectations about the percentage of others in one's field that consider carbon pricing to be a "very or extremely important" instrument in a climate policy mix. Most discipline clusters make average estimations of >50%, with environmental and other economists and legal scholars expecting the highest prevalence of importance among peers (78%). Researchers from mathematics and computer science, in contrast, expect support of <50%. Next, we compare these social expectations of one's discipline cluster with the actual importance given by researchers as described earlier in Fig. 2. To this end, we calculate the fraction of researchers in

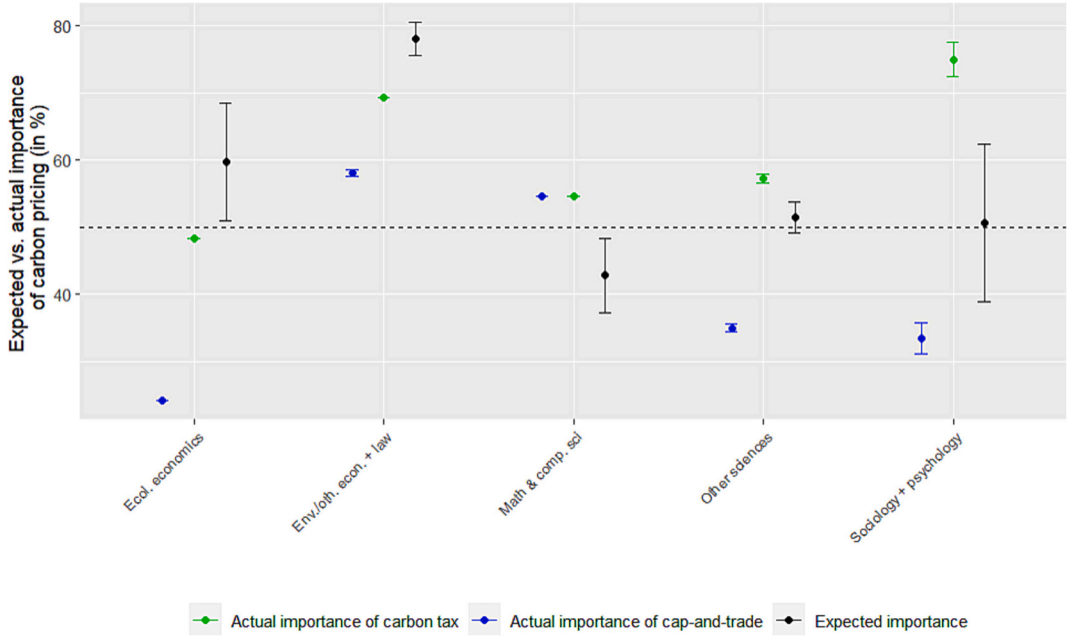

Fig. 3. Expectations about disciplinary support of carbon pricing compared with actual support. Expectations are displayed by the black dots and error bars (representing ±2 s.e.). Researchers were asked to indicate the average expected prevalence of researchers in their discipline who consider carbon pricing as very or extremely important in a national climate policy mix. Green and blue error bars show the actual fraction of researchers in each discipline cluster that consider carbon taxation and cap-and-trade, respectively, as very or extremely important. The black dashed line marks the 50% threshold, helping to quickly see if a majority (above the line) or a minority (below) judges carbon pricing as very/extremely important. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

each discipline cluster that consider carbon taxation and cap-and-trade as very or extremely important. These are shown in green and blue error bars (with error terms indicating variation within the discipline cluster) in Fig. 3, respectively. We find that some research fields, such as economics and law, overestimate the prevalence of carbon-pricing importance in their field. For sociology, psychology and other sciences, the estimation bias varies between carbon taxation or cap-and-trade. For instance, environmental and ecological economists' overestimate for both instruments, but the bias is higher for cap-and-trade. For other fields, we find both over- and underestimation. Overall, there are more fields that tend to expect lower importance of carbon pricing when comparing it to the actual importance given to carbon taxation. In following subsection, expectations about disciplinary support are used as one of the explanatory variables of researchers' individual policy views.

3.2. Further Factors Associated with Rated Instrument Importance

Next, we examine how the rated importance of each instrument is associated with the weights assigned to the four general criteria of policy performance and the beliefs of how each specific instrument performs on these criteria. In addition, we analyze the role of several general views and characteristics of researchers. Table 1 summarizes the results of six regressions based on using ordered logit estimator.[2] Regarding the general weights given to the four policy criteria, the following results are relevant. First, importance of carbon taxation and direct regulation are positively associated with considering effectiveness of policy to be important when evaluating climate policy. A high weight of the efficiency criterion is only positively associated with importance of carbon markets, which is surprising as carbon taxes are generally considered as equally efficient. Other noteworthy findings are that adoption subsidies, direct regulation and information provision are positively associated with weights assigned to the criterion of equity, while information provision and innovation support positively associate with weights assigned to feasibility.

The weights given to policy criteria play, however, a fairly minor role compared to the specific beliefs regarding how each instrument performs on these criteria, as indicated by the number and size of statistically significant relationships. The results show that importance of all instruments is significantly and positively related to instrument-specific ratings of effectiveness and efficiency. Equity ratings are positively and significantly related with importance of all instruments, except for direct regulation and carbon tax. High ratings of feasibility are positively and significantly related with importance of all instruments, except for direct regulation and information provision. A minor difference between the two types of carbon pricing is that effectiveness beliefs are more strongly linked to importance of carbon markets (in fact, the odds-ratio value for effectiveness is the highest of all performance criteria in all regressions). On average, researchers question the effectiveness of carbon markets more than of carbon taxation, which is a somewhat surprising given that the latter, unlike the first, has no quantity limit on emissions in the form of a cap (see Fig. A5).

With respect to social perceptions about disciplinary support for carbon pricing, we do not find significant relationships with the importance of most policies, with one exception: Carbon taxation tends to be rated higher in a policy mix by respondents who expected a higher agreement in their field. This suggests that beliefs about policy support in one's discipline matter even though their role is small given the value of the corresponding odds ratio. The direction of the relationship was the same for carbon markets, though without reaching statistical significance at the 5% level.

We briefly summarize findings in Table 1 about additional attitudes and characteristics. Climate worry is significantly positively associated with the importance of adoption subsidies, carbon taxation and direct regulation. The more research experience, the lower is the importance assigned to adoption subsidies and innovation support. Left-wing political orientation of respondents tends to go along with more importance given to carbon taxation and direct regulation. Regarding clusters of research fields, we find that the economics/law cluster views direct regulation as less important, while sociology/psychology is less favorable about information provision (which is also visible in the right plot of Fig. 2). Finally, women are more likely to view information provision as important. Direct regulation is more favorably viewed by researchers active in Asia and South America (compared to the reference group Africa), while innovation support only in South America.

3.3. Zooming in on the Role of Carbon Pricing

We now examine researchers' views on carbon pricing as measured by ten statements about its functioning. These statements followed a Likert-style format. Responses to them are displayed in the upper panel of Fig. 4 (which also lists the full statements). Among the beliefs with most partial or strong agreement are that consumers are more influenced by prices than environmental concerns (item 'Price sensitivity', 80%) and that carbon pricing automatically internalizes the costs of climate change (item 'Costs internalization', 71%). More diversity of opinion can be found, for example, as to whether carbon pricing promotes 'small changes' in emission reduction (item 'Small change'), with about half of the sample questioning this. Most uncertainty – counted as "Don't know" and neutral responses – was found for the statement about 'Bounded rationality' (42%). One theme emerging from participants' comments was that responses to these questions somewhat depend on the level of carbon pricing. Others suggested that responses depend on the type of carbon pricing, i.e. taxation or markets. We realized these issues before but had to limit the complexity of the survey.

The carbon-pricing statements were then used in two ways. First, we examined differences between clusters of disciplines, as shown in panel b in Fig. 4 (for reasons of space only a subset of results are shown; complete results are given in Fig. A15). For example, mathematics/computer science, environmental/other economists and social/natural scientists are more convinced that carbon pricing limits rebound than ecological economists and sociologists/psychologists. Next, we construct three clusters (based on results provided by information criteria like BIC and cAIC – see Fig. A13 in the Appendix) of respondents with similar views on the ten statements using Latent Class Analysis. We label these three clusters as carbon-pricing 'enthusiasts', 'undecided' and 'skeptics'. They make up 35%, 28% and 37% of the included respondents, respectively. The lower panel c of Fig. 4 depicts how the three clusters differ between the statements. Among the most clearly distinguishing statements are 'Innovation speed', 'Contextual policy', 'Bounded rationality' and 'Small change' (see Fig. A16). In this respect, there is also disciplinary variation between some clusters (Fig. A17), with the largest share of 'skeptics', >50%, found in sociology; several other fields have a > 50% share of 'enthusiasts', including mathematics/computer science, environmental economics, industrial ecology and psychology.

Next, we use the ten carbon-pricing statements to obtain further insight into why scientists assign distinct levels of importance to policies. To achieve this, we use the ten statements as explanatory variables in ordered logit regression analyses with as dependent variables rated importance of the two carbon-pricing instruments compared to other policies. The results are summarized in Table 2. We find that agreement with carbon pricing effectively limiting energy/carbon rebound is positively associated with giving importance to both types of carbon pricing. The rebound-limiting feature has, though, a slightly stronger influence on the judgment of taxation compared to cap-and-trade (odds

[2] To test for multicollinearity, we measured a Variance Inflation Factor for each of the regressions in Table 1, producing values in the range of 1 to 2. Since these are significantly lower than the conservative threshold of 5, problems of multicollinearity can be excluded.

Fig. 4. Distribution of responses to the ten statements about carbon pricing. Upper panel (a) shows overall distribution; middle panel (b) shows variation between the five clusters of disciplines for four statements; and lower panel (c) shows three derived opinion segments of carbon-pricing skeptics, undecided and enthusiasts for the same four statements. The response scale on the vertical axis ranges from 1 = strongly disagree to 5 = strongly agree. The complete set of graphs for panel b and c are shown in Fig. A15 and A16 in the Appendix.

ratio: 1.61 vs. 1.31); in fact, this relationship between rebound and taxation is also the strongest of all examined associations between statements and importance of any of the six instruments. Another positive effect on the importance of both types of pricing is found for the belief in the potential of global upscaling of carbon pricing. Disagreeing that carbon pricing has little impact on the speed of innovation increases the rated importance of carbon taxation, while the decentralizing nature of carbon pricing and the internalization of costs are positively

associated with the importance assigned to cap-and-trade. Several other beliefs, such as considering carbon-pricing revenues as an advantage over other instruments, show no significant associations. Comments from respondents reveal diverse views on revenues, with some indicating that revenues create new political challenges, others expressing strong preferences for how revenues should be used, and again others pointing out that instrument effectiveness ultimately reduces revenues by eroding the revenue base, i.e. emissions.

It is worth mentioning that in terms of model fit (pseudo R^2), the responses to the carbon-pricing statements explain more variation in the importance given to carbon taxation than to carbon markets (0.30 vs. 0.17). This shows that the statements are more relevant to understand scientists' attitudes about carbon taxation than about cap-and-trade, while performance criteria of policies and other researchers' characteristics better explain attitudes about carbon markets (as shown above in Table 1). With respect to other instruments, we find that believing in the effectiveness of a context-sensitive policy is consistently associated with higher importance assigned to direct regulation, adoption subsidies, innovation support and information provision. Finally, believing that carbon pricing performs worse under bounded rationality is related to higher importance assigned to adoption subsidies and information provision.

The results shown in Table 2 remain largely unchanged when including clusters of disciplines (Table A3). Perhaps one noteworthy finding is that environmental and other economists are more likely to give high importance to cap-and-trade and low importance to direct regulation, even when controlling for the ten carbon-pricing statements; this suggests that additional factors influence these policy preferences.

To complement the earlier mentioned geographical analysis, we explored a related idea, namely that the level of a carbon price implemented in different countries may correlate with the support given to this policy. We tested this hypothesis by utilizing the data published by Finch and van den Bergh (2022) which compared advertised carbon prices (reported by the World Bank) and actual prices accounting for incomplete emissions coverage. We tested our hypothesis using different subsamples of countries for which information was available. No significant correlation could be identified between support and the actual or advertised levels of carbon pricing (for further information, see Figs. A18-A20).

4. Discussion

This section discusses the main findings of the survey, namely the general preference of regulation over pricing, explanatory factors, the meaning of the carbon-pricing clusters and beliefs. In addition, we pay attention to the potential influence of methodological features of our survey on the outcomes.

4.1. Preferences for Regulation Over Carbon Pricing and Taxes Over Cap-and-Trade

To start with, regulation is considered the most important policy on average, as well as by many subsamples of disciplines. Evidence from a prior survey shows that climate scientists give more support to regulatory policies compared to carbon pricing (Rosenberg et al., 2010). Yet, a survey by Drupp et al. (2022) zooming in on carbon pricing finds little differences in recommended price levels between researchers who published in economics vs. non-economics journals. Our main result is somewhat surprising for at least two reasons. First, carbon pricing has dominated climate-policy discussions for decades, so one might expect to see more support for it. Second, a considerable amount of theoretical and empirical evidence shows that carbon pricing effectively reduces emissions (Martin et al., 2016; Best et al., 2020; and van den Bergh and Savin, 2021). Such evidence mainly comes from environmental economics, which is one of the few disciplines that gives more support for carbon taxation than direct regulation. It raises the questions whether non-economists are not aware of such evidence or find it questionable. It could also be that economists have not communicated such evidence sufficiently. This resembles a finding from a comparison of opinions by economic experts and average Americans, namely that "Interestingly, the difference is the largest on the questions where economists agree the most and where there is the largest amount of literature." (Sapienza and Zingales, 2013).

A related but more specific finding is that carbon markets come out as less popular than taxes for all disciplines, logically including environmental and other economists too. This is consistent with opinions expressed in a US survey among top economists (IGM, 2018). It should be considered, though, that carbon markets have delivered higher average prices and are the only instruments so far that have harmonized climate policy among many countries, as exemplified by the EU-ETS (Finch and van den Bergh, 2022). Notice in this regard also the high EU-ETS prices since the beginning of 2022, between 70 and almost 100 €/ton CO_2 for most of the period. Hence, there seems a divide between academia and policy practice, which merits attention in policy research. Particularly low support for cap-and-trade was expressed by ecological economists, which is surprising given that establishing limits based on climate targets is a principle that is consistent with the cap in this instrument. Perhaps some ecological economists think that this instrument is more amenable than others to manipulation by corporate interests (Spash, 2010; Savin et al., 2024). In addition, future research could be undertaken to investigate why especially European and American respondents show a preference for carbon taxation over cap-and-trade.

Future studies could also explore in more detail some peculiar discipline-related findings of our survey. For example, that the cluster of psychologists and sociologist rated carbon taxation even more positively than environmental economists and, provided a comparatively low rating of information provision. It might be tested whether this reflects an emerging understanding of fairly disappointing effects of information and nudge interventions (e.g. Bergquist et al., 2023). Of course, small sample sizes may also play a role in these particular results (see also Section 4.4 below).

4.2. Factors associated with instrument preferences

Additional findings can partially explain the rated importance of instruments. For this we assessed a variety of underlying factors. In fact, when controlling for these other factors, disciplinary differences turned out to be non-significant in many cases, as shown by Table 1. When examining associations between instrument-specific ratings of policy criteria and levels of assigned instrument importance, one key result is that carbon pricing is viewed as important when researchers also highly rate a policy's socio-political feasibility. This is in line with the argument that some people dislike carbon pricing because of its contested feasibility. For direct regulation to be supported, however, respondents need to consider it as effective and efficient, while feasibility explains different policy preferences less well.

Not only specific ratings of instruments matter. Researchers are also found to assign different weights to distinct criteria of policy performance, which in turn affect ratings of instrument importance. For example, a high weight for effectiveness is most strongly associated with importance of regulation, while a high weight for efficiency is linked to cap-and-trade. This suggests that researchers may need to make their criteria weights more transparent when giving policy advice. In fact, the underlying question here is what explains the differences in the policy criteria weights and ratings between respondents and disciplines. This merits more systematic attention in future research.

In addition to disciplines and policy criteria, our results indicate that left-wing political orientation is linked to support for direct regulation, but less (carbon taxation) or not at all (cap-and-trade) to the types of carbon pricing. Compared to other instruments, regulation is also more strongly linked to worry about climate change. These two findings suggests that pro-regulation views are slightly more driven political

ideology and the urgency of the problem. There is a long-standing fact/value debate and evidence suggests that worldviews of experts are not only linked to policy preferences, but also to so-called "empirical, technical and theoretical views" (Randazzo and Haidt, 2015). Having said that, the use of a political left-right scale is somewhat limited in an international context, where these political categories might mean slightly different things in different countries.

4.3. Carbon-Pricing Clusters and Associated Beliefs

We identify three main clusters of respondents with different views on carbon pricing, namely 'enthusiasts' (35% of respondents), 'undecided' (28%) and 'skeptics' (37%). These findings may help to nuance the debate on carbon pricing. The questions on how carbon pricing affects the speed of low-carbon innovation, how it works under bounded rationality, whether it is context-sensitive and to what extent it reduces rebound are among the ones that most contribute to distinguishing the three clusters of respondents. Since views on these questions do not diverge considerably between disciplines, we conclude that personal rather than disciplinary differences matter in how carbon pricing is perceived.

Among the various statements about carbon pricing, we find that believing that carbon pricing reduces energy rebound has the strongest association with giving support to this policy instrument. This is remarkable given that researchers, particularly economists, have traditionally not stressed rebound in motivating carbon pricing. Recent research finds that a "US$ 1.55/tCO2 increase in the tax rate reduces the CO_2 rebound effect by 1.5–5.6%." (Chen et al., 2022). In general, our survey finding could inform policy discussions about how to tackle rebound, namely by strengthening carbon pricing. Additional research is warranted on providing more insight – using quantitative studies or even meta-analysis – into how rebound and hence greenhouse gas emissions differ between pricing and non-pricing instruments and how more information about this would affect instrument support by scientists.

Furthermore, we did not find that carbon-pricing revenues – a frequently emphasized advantage of pricing over other policies – is significantly associated with rated importance of carbon pricing. Comments by respondents indicate that there are many views on the use of revenues. This finding is in line with results from a survey among economists which showed low agreement on the question of use of carbon-pricing revenues (Haab and Whitehead, 2017). Further research could try to clarify the specific role of revenues better, for example, by studying the country and contextual factors that may drive revenue-use preferences.

4.4. Sample Features

Our sample deserves some further reflection. Using somewhat general search terms, we deliberately opted for a wide sample frame to cover a broad range of scientists. This explains partly the low response rate mentioned in Section 2. The alternative option would have been to forgo anonymity of respondents and use their publicly available data, which likely would have led to even fewer responses. The present sampling approach means that we may have some respondents in our sample who are not deep experts in every posed policy question. The advantage of this approach is, however, that we can compare opinions from many fields, which otherwise would have been difficult. For example, economists presumably hold more policy-relevant knowledge than natural scientists. But even the latter, despite not having deep knowledge about climate policy, sometimes make policy recommendations, for example, when speaking about climate change to the media. Moreover, the natural scientist (to stick with the example) who selected into our survey and who published articles that include terms like "policy" are probably the ones that have more than a passing interest in policy. Of course, it would be useful to test our findings against distinctly composed samples in the future. This may also involve other expert characteristics, such as number and quality of publications, h-index, etc. To keep our survey short, we only captured research experience, which showed that respondents had on average almost 20 years of experience. Furthermore, the analysis indicates that experience generally had few significant associations with policy views. It should be noted, however, that prior surveys of researchers shows that such factors play a minor role in explaining opinion variation (Drupp et al., 2022; Andre and Falk, 2021). An additional point is that the size of some subsamples of disciplines in our survey was rather limited, these results should therefore be viewed with caution.

Finally, there is a lot of policy expertise outside academic research. This includes, among others, regulators, former government officials, business leaders in relevant areas, and environmental lawyers. Our study was limited to academic experts, but to capture this additional policy expertise, such professions could be the focus of future surveys.

5. Conclusions

Decisions of climate policymakers can be informed by researchers' advice. To obtain insight into similarities and differences between what climate researchers recommend, this study has undertaken a global survey of scientists' views on six main types of climate policies, with special attention given to the role of carbon pricing. The results demonstrate that on average all policies are viewed as important, but that the degree of support differs between (groups) of disciplines. Direct regulation comes out as being assigned the highest importance, followed by innovation support, carbon taxation, information provision, adoption subsidies, and cap-and-trade. The findings confirm previous insights that economists are enthusiastic about carbon pricing, notably taxation. However, our results also demonstrate that economists are not alone in their support for this instrument – engineers, legal scholars, psychologists, industrial ecologists and other disciplines give importance to it as well, though to a varying degree. There is relatively more disciplinary variation of views regarding cap-and-trade compared to carbon taxation, while disciplines also diverge considerably over another instrument, namely information provision. The latter may have to do with different interpretations of this policy, ranging from information campaigns to education. We identify five main clusters of disciplines that show distinct views on the relative importance of the six types of policy instruments: (i) sociology and psychology; (ii) ecological economics; (iii) a heterogeneous group consisting of various social and natural sciences; (iv) environmental and other economics, and law; and (v) mathematics and computer sciences.

We also examined perceptions of others' opinions and find that in most fields researchers *expect* majorities of their colleagues to consider carbon pricing as very or extremely important. When comparing *expected* to *actual* importance we observe that economists tend to overestimate the prevalence of carbon-pricing support in their field, while researchers from most other fields tend to underestimate it, especially regarding carbon taxation. Moreover, we identify three main clusters of respondents with different carbon-pricing views, namely so-called 'enthusiasts' (35% of respondents), 'undecided' (28%) and 'skeptics' (37%). Next, by confronting respondents with ten statements about its functioning, we elicited reasons for assigning importance to carbon pricing. The statement that carbon pricing effectively limits energy/carbon rebound is the best predictor of giving importance to this policy. Another statement strongly related to importance of carbon pricing is about its potential for global policy harmonization. We further find that importance given to all instruments except carbon pricing can be partly explained by the belief that a contextual, sector-specific policy approach is the most effective.

Overall, our findings provide evidence on how researchers and disciplines view the importance of the main types of climate-policy instruments. These findings could help to understand the main reasons behind disagreement among scientific disciplines on why one type of

instrument is better than others. Knowing how researchers from different fields weight different policy criteria, which aspects of the policies they doubt more, and how this is related to their personal views and experience could form the basis of productive interdisciplinary debate, communication and collaboration.

Author contributions

SD conceived the research, designed the survey and collected the data, and wrote the first draft of the paper.

IS participated in the conception of the research and survey design, analyzed the data and contributed to the writing and revision.

JvdB participated in the conception of the research and survey design, and contributed to the writing and revision.

Ethics

The research project was approved by the Committee on Ethics in Animal and Human Experiments of the Autonomous University of Barcelona (reference number of the case: 5758). The authors declare they have adhered to all ethical regulations.

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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 and Code Availability

Data and code for this study are available at: https://github.com/IvanVSavin/GlobalScientistsSurvey.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2023.108098.

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