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# Carbon pricing – perceived strengths, weaknesses and knowledge gaps according to a global expert survey

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## Abstract

Researchers from different disciplines have different opinions about carbon pricing. To better understand the reasoning behind these perspectives, we utilize responses to three open-ended questions from a global survey among almost 800 researchers from a wide variety of fields who published on climate policy. Using methods from computational linguistics, we classify reflections of researchers on the main strengths and weaknesses of carbon pricing compared with other policy instruments in seven and six topics, respectively. The results indicate that the main perceived strengths of carbon pricing are that it is effective and efficient at reducing emissions, gives clear investment incentives, decentralizes policy, among others. The main perceived weaknesses of carbon pricing are related to its potentially regressive effects on households, low social-political support, and amenability to manipulation—to name a few. Surprisingly, not all these perceptions are in line with established theory and empirical evidence. Finally, we collect suggestions for future research. Among nine frequently mentioned themes are improving public understanding of carbon pricing, political acceptability, synergies with other policies, long-term effects, and implementation in an equitable way in developing countries and worldwide. In addition, we highlight several less frequent but arguably innovative research avenues. Finally, we report to what extent the identified topics on strengths, weaknesses and knowledge gaps are significantly related to academic experience, gender, GDP per capita in the countries of origin and residence of the survey participants, and perceived importance of carbon pricing. This information helps identifying key differences in views within the scientific community on carbon pricing and can guide communication between fields aimed at reaching more consensus on climate policy.

## 1. Introduction

Countries tend to employ a range of policy instruments to achieve their climate goals. Carbon pricing in the form of taxation or trading is a key instrument according to many studies and experts. Nevertheless, apart from resistance in the general public (e.g. Douenne and Fabre 2020, Maestre-Andrés *et al* 2021), there is also continuing scientific debate about the strengths and weaknesses of this policy instrument (Tvinnereim and Mehling 2018, Mildenberger and Stokes 2020, Rosenbloom *et al* 2020, for an overview, see van den Bergh and van Den Botzen 2022).

In recent years, surveying large samples of researchers and experts has served to study consensus and controversy about aspects of climate change (Carlton *et al* 2015, Cook *et al* 2016). The method has also been used to study agreements and disagreements on questions of climate and environmental policy (Haab and Whitehead 2017, Drews *et al* 2024). In addition, it has been employed to elicit ideas about future research (Sutherland *et al* 2011).

While a policy instrument such as carbon pricing is already well-studied, new developments and trends emerge over time. Expert surveys are a perfect tool to identify these. In addition, they serve to validate existing research findings and trajectories.

Surveys, whether of scientists or citizens, typically rely on closed-ended questions. Recently, a small but growing literature has emerged which analyses responses to open-ended questions with techniques of computational linguistics. Most of such studies examine public opinion (Tvinnereim and Fløttum 2015, Matschoss *et al* 2019, Savin *et al* 2020, Enria *et al* 2021). However, one study used the method to analyze scientists' views, namely on economic growth and its relationship with environmental sustainability (Savin *et al* 2021). The main advantages of using open- instead of closed-ended survey questions is that they allow uncovering unexpected insights and better understanding of the reasons for expressed opinions by revealing beliefs and narratives among experts and the general public (Andre *et al* 2022). The quantitative analysis of such data through computational techniques provides for an objective and systemic approach to analyze verbal responses from a large number of survey participants. This complements traditional subjective assessments of these kinds of responses.

While samples of previous surveys on climate policy tend to include only economists (e.g. Howard and Sylvan 2015, Haab and Whitehead 2017), this study draws on data collected by a survey of 789 scientists from many countries and with backgrounds in a wider range of disciplines. It was designed with having three objectives in mind. First, to investigate what scientists consider as the main strengths and weaknesses of carbon pricing compared to alternative policy instruments such as direct regulation (e.g. standards, quotas), information provision (e.g. ecolabels, education), innovation support (e.g. R&D subsidies) and adoption subsidies. Second, to elicit ideas and directions for further research on this policy instrument. Third, to examine how these opinions about carbon pricing and research avenues vary with socio-demographic and disciplinary differences among researchers. The latter can help to understand how opposing views on climate policies are distributed among researchers, in order to foster constructive debate with the rest of the community.

Understanding scientists' views about climate policy is vital for at least two reasons. First, because such views are at the basis of information for and advice to policymakers (Javeline and Shufeldt 2014). Second, because public opinion about climate policy is partly shaped by information from scientists (Maliniak *et al* 2020). In fact, the general public nowadays expects scientists to be outspoken on climate policy and communicate their findings clearly to policymakers and journalists (Cologna *et al* 2021). Moreover, universities encourage such public engagement of their staff. This is in part 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).

## 2. Methods

### 2.1. The survey

To create a sample of researchers to present the survey to, we searched the academic database Web of Science for articles published between January 1st 2016 and June 22nd 2021 using query terms that focused on carbon pricing instruments in particular or climate policy more generally ('carbon pric*' OR 'carbon tax*' OR 'cap-and-trade' OR 'climate polic*' OR 'mitigation of climate change' OR 'climate change mitigation'). This resulted in 10 822 documents and 15 070 unique email addresses.

The survey was programmed in the survey tool Cmix by Dynata and improved based on feedback from pretesting involving 25 researchers from different fields. The survey was undertaken from mid-September to the 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). The survey resulted in a final sample of 789 completed responses. Figure A1 in the appendix shows the country of residence and origin of the survey respondents, demonstrating considerable global coverage and focusing more on the OECD countries. Furthermore, the average number of years after PhD of survey respondents is 18.5 (see table A1 in appendix A), indicating considerable research experience. Additionally, most of our participants come from environmental economics (21%), natural science (14%), political science and engineering (each 11%) and sustainability transition (10%). This arguably reflects major countries and scientific fields currently studying climate policy. Moreover, our survey also measured respondents' views in the growth-vs-environment debate. Using the same data set, King *et al* (2023) find that 27.1% are in favor of green growth, 44.8% prefer agrowth and 28.1% support degrowth. This distribution is fairly consistent with that of prior surveys using multidisciplinary samples (Drews *et al* 2019, Koskimäki 2023).

After an introductory page and a request for consent, two questions eliciting respondents' self-reported research field and topics were posed. While most participants selected one of the predefined fields (e.g. economics or sociology), about 140 respondents did not select these but instead 'other', followed by entering their own description of a research field. Based on this information we either assigned them to already predefined categories (for example, 'public policy' to political science), or constructed three new categories: 'other environmental social science'

($n = 43$), where we aggregated people researching on history or philosophy, 'industrial ecology' ($n = 12$) and 'agriculture/forestry' ($n = 25$). Table A1 in the appendix provides summary statistics for the research fields and other characteristics of the respondents.

The response rate of the survey is 5.2%, which is due to several reasons. First, some researchers changed their email address since they published, which resulted in many emails not being delivered. Second, many emails were likely directed to the spam folders. Finally, out of 3422 people who started the survey, most dropped out early on, possibly as they either did not have enough motivation to complete it (Steinbrecher *et al* 2015), or because the survey was relatively long. Despite these reasons, our response rate is comparable to other surveys of scientists with a relatively wide sample frame (e.g. Aranzales *et al* 2021).

Further discussion is necessary regarding our survey sample. We chose relatively broad search keywords on purpose, which resulted in a wide sample frame that encompasses a diverse range of scientists. As a consequence, the abovementioned response rate is relatively low. Furthermore, it is possible that some respondents in our sample may not be experts in every policy question posed. Nonetheless, our approach allows us to compare views across multiple research fields, which would have otherwise been difficult. However, it is worth to validate our findings against other academic samples in the future. This validation process could take into account further expert characteristics such as the quantity and quality of their research output or their number of citations. To keep our survey concise, we only asked about research experience. The collected answers suggest two things: First, our survey participants had an average of nearly 20 years of research experience after their PhD, which implies that they are representative of the study population of scientists. Second, research experience has little correlation with policy views. An alternative approach would have been to ask for names of researchers and utilize their publicly available data, but we believe this would have reduced the response rate even further. It is worth stressing, however, that previous surveys indicate that these factors have little explanatory power for opinions (Andre and Falk 2021, Drupp *et al* 2022). Furthermore, it is important to interpret the results of subsamples from certain disciplines with caution, as their sizes were relatively small. Further surveys should be performed to ensure robustness of our findings. Finally, it is worth comparing our results with other studies concentrated less on economic discipline and OECD countries. One possible way to do this is through exploring Twitter data (see, e.g. Bergamini *et al* 2023).

At the beginning of the survey respondents were asked to judge the importance of six policy instruments in a climate-policy mix of a country (on a five-point scale of importance). These instrument types included direct regulation, carbon taxation, cap-and-trade, adoption subsidies, innovation support, and information provision, motivated by classifications in prior studies (e.g. van den Bergh *et al* 2021).

The survey then moved from questions about multiple instruments to the specific role of carbon pricing. This part started by presenting to respondents the following contextual statement: '*There is considerable debate about the specific role of carbon pricing (carbon tax or cap-and-trade) in the climate policy mix.*'. After this, the first two open-ended questions were formulated as follows:

'*What do you think are the main strength(s) and weakness(es) of carbon pricing compared with other instruments? We would like that you take your time to answer this question and, if possible, write some sentences. All kinds of answers are welcome.*

*Strength(s): [_____open text field_____]*

*Weakness(es): [_____open text field_____]*'

After this, the third open-ended question was posed:

'*Can you indicate knowledge gaps about carbon pricing that deserve attention in research? We would like that you take your time to answer this question and, if possible, write some sentences. All kinds of answers are welcome*'.

All open-ended questions were formulated rather broadly to stimulate researchers to freely formulate their perception about the subject. The minimum response was set to five characters. A total of 7, 6 and 27 respondents essentially admitted they did not know how to answer the three respective open questions, respectively. However, this is consistently below 5% of our sample. This approach is in line with previous studies using surveys for structural topic modeling (STM) (Tvinnereim and Fløttum 2015, Savin *et al* 2022a). Finally, respondents were presented several other questions, such as about their research and personal background, their years of research experience, gender and country of origin and residence. Appendix B shows the complete questionnaire.

### 2.2. Data analysis

Below we describe the approach of topic modeling—which is based on natural language processing—, used to analyze the responses to the open-ended questions. The average (median) length of responses to the three open questions about strengths, weaknesses and knowledge gaps is 18 (12), 24 (15) and 22 (14) words, respectively (see figure A2 in appendix A for more details). Before proceeding with application of topic modeling to the data, we cleaned the responses in the following ways (see also Savin *et al* 2023):

- we substituted capital by lower-case letters;
- we converted words to their dictionary form (lemma) using Wordnet-based lemmatization;

- we established frequent expressions in the form of bigrams, like 'cap_trade', 'low_income' or 'long_term' using Normalized Pointwise Mutual Information (Bouma 2009);
- we removed stop words (like 'a'. 'the', 'we', 'I');
- we eliminated words shorter than three characters or observed in less than six answers.

This procedure resulted in 43/44/47 discarded replies for the first/second/third open-ended question, while the remaining responses contain 146/203/165 unique words and 4220/5251/4121 if counting words with repetition.

To classify the resulting textual responses into main themes, we employ (STM, Roberts *et al* 2019). Topic-modeling algorithms attributes words into topics based on their co-occurrence across textual responses. Therefore, unlike a simple word count, topic modeling considers words in their context, i.e. other words they appear with (see Blei 2012, Savin *et al* 2022b) for a detailed discussion). For example, observing the words 'unfair', 'pricing' and 'consumer' next to 'poor' and 'rich' in the topic with a label 'Increases inequality' (see table 1 below) implies that these words appeared a lot together in this topic, and that some scientists believe that carbon pricing can increase inequality in society. STM was developed particularly for short texts typical for survey responses to open questions and can incorporate additional data about the responses, such as the scientists' academic experience, gender, scientific field, and ratings of carbon tax and carbon market in a climate policy mix. This allows the method to formulate a superior statistical model on where to expect differences between responses and better identify topics (see Roberts *et al* 2014, Savin *et al* 2020). We selected the aforementioned five covariates since they have minimum missing observations, in contrast to, e.g., climate concern or political orientation, whose inclusion would reduce our sample by around 100 observations. The rating of the importance of carbon taxation and cap-and-trade together produce 67 missing observations, but these variables are vital to distinguish scientists' attitudes to carbon pricing.

Applying STM and assigning each response to different topics with different weights, so-called 'topic prevalences' that sum up to one, we must decide upon the number of topics $k$. In line with earlier literature (Tvinnereim and Fløttum 2015, Savin and Teplyakov 2022, Savin 2023), we run STM for the number of topics being between three and ten and evaluate how the model performs in terms of

1. Heldout log-likelihood, i.e prediction accuracy,
2. Exclusivity, i.e. extent to which popular words from topics overlap
3. Semantic coherence, i.e. degree to which words from the same topic appear in same replies.

Figure A4 in appendix A summarizes the results for the three open-ended questions. For strengths of carbon pricing we arrived at 7 topics, for weaknesses—at 6 topics, and for further research—at 9.

## 3. Results

### 3.1. Perceived strengths of carbon pricing

Table 1 summarizes the seven topics identified from the first open question about perceived strengths of carbon pricing by scientists (figure A9 in the appendix A presents their word clouds). In the remainder of the text the notation $x$T$y$ (with $x$ and $y$ numbers) denotes topic (T) $y$ from the $x$th open-ended question. It shows the 10 most discriminating (frequent and exclusive) words for each topic together with a fraction of an illustrative response (having a large prevalence of that topic) along with the share of the overall set of responses belonging to each of the topics (topic proportion) and the scientific fields which stressed the topic significantly more (or less) than environmental economists, the field with the largest number of survey participants. After exploring many more illustrative responses, which we do not include here for brevity reasons, we arrived at topic labels that reflect the main themes well and concisely. For example, 1T6, which suggests that carbon pricing represents a flexible regulation instrument, has the words 'easy_implement', 'regulation', 'mechanism' and 'pollution' come out strongly. In fact, most topics (1T1, 1T2, 1T4, 1T5) refer in one way or another to the environmental effectiveness of the policy, describing different channels how this can be achieved (e.g. through reinvesting tax revenues, giving clear price signal to the market participants, etc).

Figure A5 in appendix A presents correlations between topic prevalence across responses. These indicate whether specific pairs of topics appeared often or seldom together in responses. As one can see, topics 1T1 and 1T3 (about effectiveness of the policy and the polluter-pays principle) and 1T2 and 1T7 (about the ability to reduce emissions and cost-effectiveness) are strongly correlated. As opposed, 1T7 is negatively correlated with 1T3 and 1T4 (about providing incentives to abate).

We proceed with a regression analysis quantifying factors explaining the variation of topic prevalences among the respondents. As explained in the Methods section, we selected five covariates to form the STM topic model and now use them here in a linear regression model specified for each of the seven topics (indexed by $k$) as demonstrated below. The variable scientific field is coded as a factor variable resulting in coefficients for every category, except for environmental economics which as the largest field in our survey is used as a benchmark.

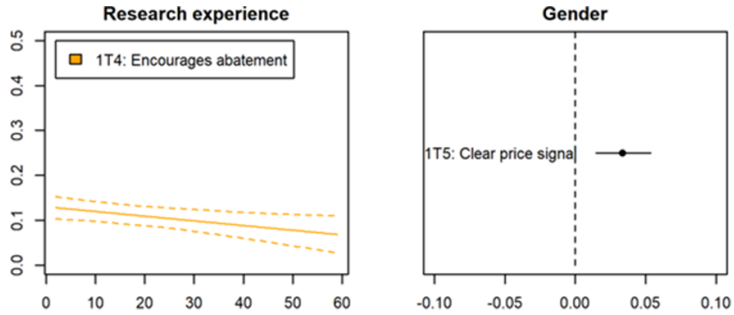


**Figure 1.** Effect of covariates on topic prevalence for perceived strengths of carbon pricing.
*Note:* coefficients generated by a regression where the outcome variable is the topic prevalence in each response. Point estimates of selected covariates on topic prevalence are plotted holding all other covariates constant. The plot for research experience shows the number of years of research experience on the horizontal axis. The plot for gender shows mean difference in topic proportions between male and female (a positive value on the horizontal axis indicates a larger prevalence for male respondents). Only results significant at least at the 5% level are displayed. Results for all topics are available in appendix A.

$$\begin{aligned} Topic\,prevalence_k \sim\ & Constant_k + Research\ experience \\ & + Gender + Scientific\ field \\ & + Carbon\ tax\ rating + Cap-and \\ & - trade\ rating + Residual_k. \end{aligned} \quad (1)$$

The full set of results is reported in tables A2–A4 in appendix A, while figure 1 shows significant results (at the 5% level) for research experience and gender. Results for scientific field are presented in the corresponding tables that summarize topics (tables 1–3), while results for the rating of carbon tax and cap-and-trade are discussed further below in figures 2 and 3. Whenever we observe a prevalence of topic $k$ to increase (decrease) across a given covariate, this implies that responses from people with a larger (smaller) value on that covariate expressed that topic more strongly. Given that these covariates were evolving in paralell with the scientists themselves, our results should be understood as a correlation analysis only. We find that 1T5 on 'clear price signal' is expressed significantly more often by male scientists, while topic 1T4 on 'encouraging abatement' by scientists with relatively little research experience.

Furthermore, since we have information on the countries of origin and residence of the respondents, we statistically can test if researchers from richer or poorer countries tend to stress particular topics more or less. Inspired by King *et al* (2023), we added information on GDP per capita (in current prices and adjusted for purchasing power parity), Gini index (all sourced from the world economic outlook database), and inequality-adjusted human development index (IHDI, sourced from UNDP human development data). The results are shown in figure A12 in the appendix A. It indicates that topic 1T6 on flexible regulation tends to be expressed more by scientists from lower income countries. This may be because for these countries it is more important to assure cost-effectiveness.

## 4. Perceived weaknesses of carbon pricing

Table 2 summarizes results for the question on perceived weaknesses of carbon pricing (figure A10 in the appendix A presents their word clouds). Many scientists name unequitable effects this instrument causes (2T1 and 2T3) and consequently low public and political support this climate policy instrument has (2T4 and 2T5). This is in line with earlier literature stressing equity and feasibility as main potential pitfalls of the instrument. The remaining two topics deal with the difficulty to uniform implementation of the policy without exemptions and manipulation (2T2) and its global upscaling (2T6).

Respondents also connect these weaknesses together. Thus, scientists stressing regressive effects (2T1) also often stress its political feasibility problem (2T4), while those who discuss vulnerability to manipulation (2T2) are likely to mention the difficulty to implement globally (2T6) (see figure A6 in appendix A).

It is interesting that the latter two weaknesses (vulnerability to manipulation and global implementation) are stressed more by researchers with fewer years of academic experience. Scientists with more experience, in contrast, stress more regressive effects on households (figure A15). Finally, female scientists are more likely to stress the problem with political feasibility, while men discuss issues like growing inequality, which is in line with prior research showing that distributive effects are considered more important by female researchers (Maestre-Andrés *et al* 2021).

In addition, figure A13 in the appendix A shows that topic 2T4 politically infeasible is expressed more by researchers from richer countries, while 2T6 difficult to implement globally, in contrast, more by academic experts from poorer states. The former makes some sense given that in the OECD countries there has been strong opposition to carbon taxation (Dolphin *et al* 2020, Levi *et al* 2020).

**Table 1.** Topics identified for responses to the first question on perceived strengths of carbon pricing.

| | Topic label | Most discriminating terms and illustrative responses | Topic prevalence | Discipline focus |
|---|---|---|---|---|
| 1T1 | Financial support | Potential, stakeholder, help, effectiveness, achieve, ghg, way, combine, principle, financial<br>'collect money to subsidize transformations towards carbon-free economies.—stimulate research and investments in innovations'. | 12.1% | Less in sust. transition studies |
| 1T2 | Effective emission reduction | Reduction, relatively, give, high, place, emission, effective, externality, theoretically, tax<br>'They can have a very direct and quick impact on emissions because they directly affect consumption whereas many other instruments are weaker, being more upstream and having longer latency' | 16.7% | Less in oth. economics |
| 1T3 | Makes polluter pay | Clear, polluter_pay, environmental, market, drive, project, climate_change, innovation, make, incentive<br>'makes polluters pay, forces behavior change' | 13.6% | — |
| 1T4 | Encourages abatement | Economy, change, behavior, effect, energy, emitter, encourage, innovate, development, transition<br>'It provides a direct economic disincentive for businesses and industries to stop using fossil fuels, and a direct incentive to move to green energy and green practices' | 15.0% | More in ecol. economics, engineering, geography, nat. sciences, oth. env. soc. sci., psychology and sust. transition |
| 1T5 | Clear price signal | Low, cost, option, impact, least, price, include, generate, sector, carbon<br>'Putting a price on carbon sends the appropriate price signals to the producer/consumer' | 18.2% | Less in geography and political sci. |
| 1T6 | Flexible regulation | Regulation, mechanism, create, global, good, easy_implement, get, work, carbon_pricing, pollution<br>'It is flexible, meaning that the points of regulation can decide how to comply with the regulation as well as technology neutral so it allows for the development of different new technologies'. | 12.0% | Less in sust. transition Studies |
| 1T7 | Efficient instrument | Efficient, strength, implement, cap_trade, limit, important, government, find, promote, benefit<br>'The primary strength of carbon pricing comes from its efficiency'. | 12.4% | Less in sust. transition studies |

*Note:* the terms shown are those that are the most frequent as well as exclusive to each topic. Fractions of illustrative responses are chosen from the ten responses with the highest topic prevalence. Discipline focus is taken from the regression analysis reported in table A2 in appendix A, where env. economics is the benchmark group.

Inspired by the analysis in Savin *et al* (2022a, see figures 2 and 3), we then plot the identified topics on main strengths and weaknesses of carbon pricing depending on how important our survey participants rated carbon taxation and cap-and-trade as a constituent element of a country's policy mix (on a Likert scale from 1 to 5 where 1 is 'unimportant' and 5 'extremely important'). In figure 2, the position of each topic on the $X$- and $Y$-axes reflects the weighted average (i.e. share of the topic in the response multiplied by the response of the scientist on the closed question regarding importance of the instrument in the policy mix) of the responses on the corresponding closed questions. The two black lines in figure 2

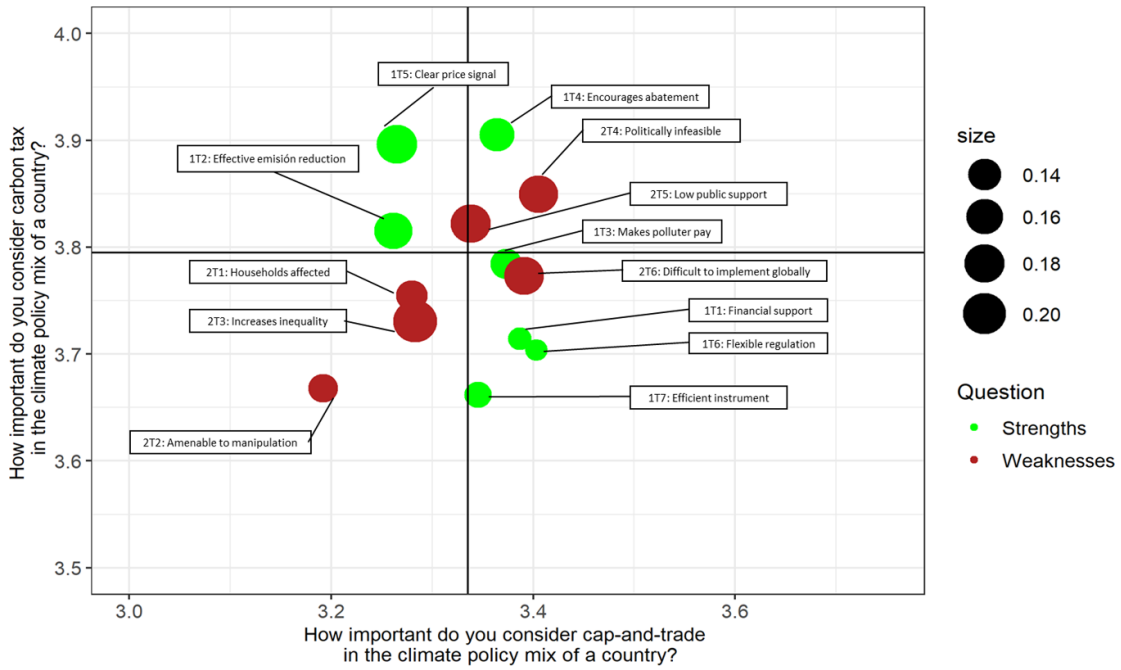


**Figure 2.** Perceived strengths and weaknesses of carbon pricing depending on rated importance of carbon tax and cap-and-trade in a country's policy mix.
*Note:* green color indicates topics from the first open question (about strength of carbon pricing), and red from the second one (weaknesses). Size of the topic reflects its prevalence in the overall set of responses. Position of each topic on the *X*- and *Y*-axes is the weighted average response on the Likert scale from 1 (unimportant) to 5 (extremely important) on the corresponding closed questions.

reflect the average importance of carbon tax and cap-and-trade in a policy mix according to the respondents. Therefore, topics plotted in the top-right quadrant, for example, are typically stressed by people who valued both forms of carbon pricing as relatively more important compared to their peers. The two colors indicate which set of topics we are referring to (green and red for strengths and weaknesses, respectively), while the sizes of each bubble proxies the topic proportion in the whole set of responses.

The first thing we can notice from figure 2 is that carbon taxation is rated considerably higher than cap-and-trade in a country's policy mix. In figure A7 in appendix A we plot how support of carbon tax and carbon market in each of the 15 scientific fields corresponds to the average across all disciplines. It shows that environmental economists rate both instruments above average, psychologists and researchers in sustainability transition rate highly a tax but not cap-and-trade, scholars from mathematics/ computer science and law do the opposite, and ecological economists and political scientists rate both instruments below average.

In addition, one can see that scientists who rate both pricing instruments relatively high say that carbon pricing encourages abatement (1T4) but is politically infeasible and has low public support (2T4 and 2T5). Furthermore, scientists who evaluate carbon taxation but not cap-and-trade relatively high stress that carbon pricing gives clear price (1T5) signal and reduces emissions (1T2). Researchers who in contrast rate cap-and-trade higher than carbon tax speak more about decentralizing policy (1T6), incentives to invest in low carbon transition (1T1), the possibility to make polluter pay (1T3) and efficiency of the policy (1T7). Those who dislike both carbon pricing stress that it is vulnerable to manipulation (1T2) and has regressive effects on consumers (2T1 and 2T3).

It is important to realize that some of the perceptions and opinions are not in line with evidence from empirical studies. For example, standards are more likely than taxes to be manipulated (Macho-Stadler 2008), as is illustrated by dieselgate. In addition, adoption subsidies, such as for electric vehicles and rooftop solar PV, and efficiency standards benefit especially more affluent households (Grösche and Schröder 2014, Herrmann and Savin 2017, Levinson 2019, Konc *et al* 2022), without providing any revenues to compensate for regressive effects. A particularly surprising result is that people who consider cap-and-trade as more important in a policy mix are more likely to stress that carbon pricing has the weakness of being difficult to be globally implemented; but cap-and-trade has actually shown a great potential for international harmonization through carbon pricing—witness the current EU-ETS system which harmonized policy in 31 countries (all EU members along with Iceland, Liechtenstein and Norway).

**Table 2.** Topics identified for responses to the second question on perceived weaknesses of carbon pricing.

| | Topic label | Most discriminating terms and illustrative responses | Topic prevalence | Discipline focus |
|---|---|---|---|---|
| 2T1 | Households affected | Measure, household, tax, high, energy, particularly, bad, far, less, distributional 'Will have regressive impact on households' | 13.5% | Less by engineering, agri./forestry, math. & somp. sci., natural sci., oth. env. soc. sci. and sust. transition. |
| 2T2 | Amenable to manipulation | Climate, system, negative, cap, vulnerable, issue, work, ineffective, problem, effective 'Not effective if cap is not lowered and emission permits are issued for free. Obsolete technologies are maintained because they allow the issuance of carbon credits. Many opportunities for fraud'. | 13.0% | More by natural sci., oth. env. soc. sci. and sust. transition |
| 2T3 | Increases inequality | Pricing, consumer, people, rich, cost, product, poor, efficiency, increase, unfair 'Carbon tax places an unfair burden on the lower income population, while not necessarily dissuading the higher income from making behavioral changes'. | 20.7% | More by engineering, geography, natural sci. and oth, economics |
| 2T4 | Politically infeasible | Regressive, political, equity, feasibility, feasible, hard, low_income, lack, politically, inequality 'politically infeasible, and publicly unpopular' | 17.4% | Less by ecol. economics, engineering, law, natural sci., oth. env. soc. sci. and sust. transition |
| 2T5 | Low public support | Public, low, investment, effectiveness, reduce, implement, implementation, difficult, little, limited 'hard to implement due to relatively low public support in some countries (e.g. Switzerland)' | 18.0% | Less by law and natural sci. |
| 2T6 | Difficult to implement globally | Country, develop, company, different, economic, industry, lead, become, price, opposition 'Difficult to implement globally and in an equitable way -difficult to get agreement among the different countries. Difficult to account for international trade/products from different countries' | 17.4% | More by engineering, natural sci., oth. env. soc. sci. and sust. transition |

*Note:* the terms shown are those that are the most frequent as well as exclusive to each topic. Fractions of illustrative responses are chosen from the ten responses with the highest topic prevalence. Discipline focus is taken from the regression analysis reported in table A3 in appendix A, where env. economics is the benchmark group.

## 5. Perceived knowledge gaps about carbon pricing

Table 3 presents results for perceived knowledge gaps about carbon pricing (figure A11 in the appendix A presents their word clouds). These can be divided into three groups:

- understanding either by scientists (3T2) or general public (3T4) on how carbon pricing works and how to make it acceptable (3T7), and implemented globally (3T5),
- how to differentiate carbon price for different sectors (3T1) and whether to regulate emission at the source (3T3),
- how to assess long-term effects (3T8), including through more realistic models (3T6) to understand whether this instrument can eventually lead to zero emissions (3T9).

Less experienced researchers tend to stress more the knowledge gap regarding differentiated carbon pricing (3T1), while more experienced ones—lack of realistic empirical models (3T6). Female scientists stress more often whether to regulate emissions at the source (3T3), while male ones—the lack of understanding how carbon pricing works (3T2) and how to implement it globally (3T5). See figure A16 for more details.

**Table 3.** Topics identified for responses to the third question on perceived knowledge gaps about carbon pricing.

| | Topic label | Most discriminating terms and illustrative responses | Topic prevalence | Discipline focus |
|---|---|---|---|---|
| 3T1 | Differentiated carbon price among sectors | Different, price, sector, high, set, individual, limit, region, specific, political_economy<br>'Carbon price per sector, e.g. easy to skip meat for a meal, and also healthier, carbon price can reflect the real climate change cost and even higher. Hard not to use your car when you are on the country side, so carbon price may be lower for those who cannot avoid some trips' | 12.9% | Less in geography |
| 3T2 | Policy functioning with other instruments | Instrument, support, effectiveness, environmental, climate, impact, policy, understand, interaction, risk<br>'understanding the interaction of pricing instruments with other climate policy instruments' | 12.6% | Less in natural sci., more in political sci |
| 3T3 | Regulating emissions at the Source | Tax, issue, key, cap_trade, source, question, carbon, efficiency, implementation, point<br>'Carbon source, and how to mitigate carbon release at the source' | 14.6% | Less in engineering, Geography, oth. economics, oth. snv. soc. ssci. and sust. transition |
| 3T4 | Improve public understanding | Market, example, link, solution, pricing, negative, people, analysis, clear, focus<br>'Communicating the policy and science behind carbon pricing would be critical in getting understanding from the public's point of view as well as politicians'. | 9.6% | More in natural sci. |
| 3T5 | Global and equitable implementation | Equity, area, measure, good, regulation, develop_country, change, important, implication, innovation<br>'The most important gap is the border taxation, but it will remain a gap as nobody know how to implement taxation at borders and the reaction of other countries' | 8.8% | Less in Ind. ecology, law, natural sci. and sociology, more in oth. env. soc. sci. and sust. transition |
| 3T6 | Better models of carbon pricing | Increase, model, regional, little, need, effort, tool, acceptance, develop, affect<br>'carbon pricing needs to be unpacked as otherwise it is too abstract, primarily evaluated through economic models (rational choice), and entirely oblivious to design and implementation issues' | 9.0% | More in geography and natural sci. |
| 3T7 | Political acceptability | Political, effect, problem, climate_change, design, exist, carbon_pricing, economy, direct, energy<br>'Advocates of carbon pricing need to be aware of the formidable barriers to this solution to the emissions problem, such as the power of oil companies in the political process' | 14.1% | More in geography and political sci., less in math. & comp. sci. |
| 3T8 | Long-term effects | Gap, global, benefit, consumer, real, long_term, within, behavior, cost, ensure<br>'how much pricing actually affects consumers' and companies' decisions? This should be differentiated between short-term and long-term' | 8.4% | More in engineering, natural sci., oth. env. soc. sci and sust. transition |

(Continued.)

**Table 3.** (Continued.)

| | Topic label | Most discriminating terms and illustrative responses | Topic prevalence | Discipline focus |
|---|---|---|---|---|
| 3T9 | Reaching zero emissions | Emission, revenue, knowledge, data, reduction, base, zero, inzformation, practice, use<br>'The challenge of getting to zero emissions is a major one. Carbon pricing delivers immediate emissions reductions on the margin and can significantly alter the energy mix, but would it get us to zero?' | 10.0% | Less in oth. economics, oth env. soc. sci. and sust. transition. |

*Note:* the terms shown are those that are the most frequent as well as exclusive to each topic. Fractions of illustrative responses are chosen from the ten responses with the highest topic prevalence. Discipline focus is taken from the regression analysis reported in table A4 in appendix A, where env. economics is the benchmark group.

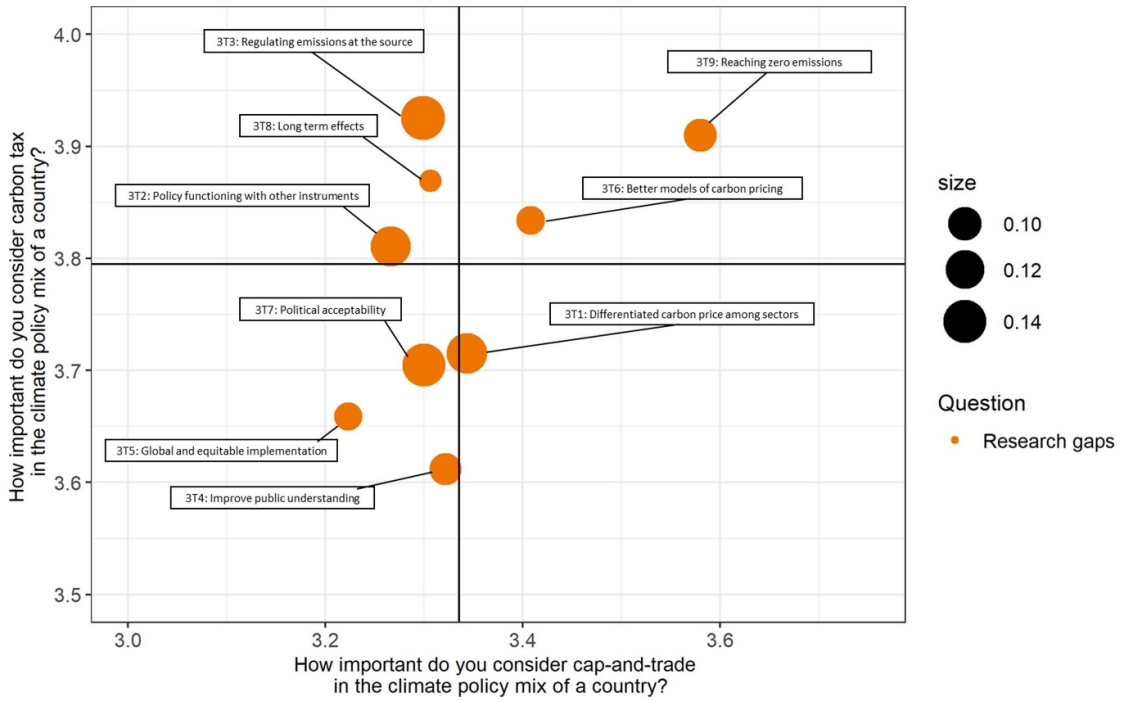


**Figure 3.** Perceived knowledge gaps in research about perceived carbon pricing depending on rated importance of carbon tax and cap-and-trade in a country's policy mix.
*Note:* size of the topic reflects its prevalence in the overall set of responses. Position of each topic on the *X*- and *Y*-axes is the weighted average response on the Likert scale from 1 (unimportant) to 5 (extremely important) on the corresponding closed questions.

Regarding which knowledge gaps tend to be frequently mentioned by the same people, the strongest pair is between how carbon pricing works (with other instruments) and in different sectors (3T1 and 3T2). A less common pair of gaps is improving public understanding and reaching zero emissions (3T4 and 3T9). In contrast, the problem of global implementation (3T5) is rarely mentioned together with public understanding (3T4) or reaching zero emissions (3T9) (see figure A8 in appendix A).

Furthermore, figure A14 in the appendix A shows that topic 3T6 on more realistic models is expressed more by researchers from poorer countries, while 3T8 on long-term effects, in contrast, by researchers from richer ones. The first can be explained by the fact that fewer models are available for lower income countries to study climate policy, whereas in the richer countries a lot of research on this has already been undertaken. The second finding could be explained by the fact that carbon price has been mostly implemented in richer countries, and people are interested more in what long-term changes this policy instrument can produce.

Figure 3 plots topics on the perceived knowledge gaps among surveyed scientists depending on how the respondents rated carbon tax and cap-and-trade in a country's policy mix. What we find is that those who rank both carbon pricing options above average are mostly interested in whether it is enough to reach zero emissions (3T9) and suggest developing more

**Table 4.** Relevant and innovative suggestions for further research on carbon pricing.

| Research direction | Suggestions for further research (theme or question) | Our comments |
|---|---|---|
| Policy impact | *Impact of really high carbon prices*<br>*How to increase feasibility and political acceptance for very high prices (prices that are actually necessary for achieving the climate targets)?* | A few respondents mention this. Existing models can in principle calculate this, although perhaps not all relevant impact categories or response behaviors are adequately represented. Of course, it is widely accepted now that we will not implement high prices but follow at best a gradual rising path of carbon pricing, allowing the economy to adapt. (McGrath and Bernauer 2017). |
| | *Will carbon pricing change consumer preferences?*<br>*Do rich people really change their consumption because of carbon taxes?* | The topic of endogenous preferences has become more popular in the last few years but there are still few studies discussing the implications for policy design (Mattauch *et al* 2022). |
| | *Impact of carbon pricing on inflation* | Holds also for other instruments which increase prices/costs indirectly. Recently Moessner (2022) has shown that carbon pricing has a small but significant effect on energy and food CPI inflation. |
| | *Pricing other GHG emissions than CO2, such methane in agriculture* | The problem here is monitoring and control, as these emissions are not well controlled by charging some input, such as fossil fuels in the case of energy-related emissions (Dragicevic 2021). |
| | *Quantification of effects of carbon pricing with boundedly rational agents.* | Some publications address this (e.g. Niamir *et al* 2020), but more research seems indeed desirable. |
| Policy acceptability | *How to better communicate the benefits of carbon pricing to citizens/voters, notably in combination with revenue recycling* | Some respondents mention this issue in some form. Following guides like by Marshall *et al* (2018) might contribute to more social-political feasibility of high carbon pricing. |
| | *Do voters prefer really high carbon prices or outright bans.* | Of course, this assumes that one can divide goods in high-carbon (banned) and low-carbon ones (not banned), whereas in reality goods and services show a broad range between these extremes, in which case pricing would be more reasonable. More differences in support of different climate polices are discussed by Rhodes *et al* (2017). |
| | *How to sell it to conservative politicians and neo-liberal voters who hate the idea of any and all taxes?* | Changing preferences of actors with polarised views on carbon pricing may be indeed a daunting task (Drews *et al* 2022b), and hence is worth attention in research. |
| | *Distribution impacts of carbon pricing beyond income: young adults, parents, students, rural vs. urban households, etc.* | This topic has received some attention, but surely the impact on some social groups can be clarified better (Emmerling and Tavoni 2021). |
| | *Lobbying by fossil fuel and financial interests against carbon pricing*<br>*Why have unions and socialist parties not grasped the fact that carbon dividend systems benefit their core constituency the most?*<br>*The roles of media misinformation, political misinformation and the roles of lobby groups in public support for carbon pricing.* | Research eliciting the knowledge and preferences of such stakeholders, such as through surveys or interviews (see e.g. Hepburn *et al* 2020), might be useful here. |

(Continued.)

**Table 4.** (Continued.)

| Research direction | Suggestions for further research (theme or question) | Our comments |
|---|---|---|
| | *Is carbon pricing vulnerable to abuse by multinational companies operating in developing countries, and if so, which domestic and international mechanisms might curb such misuse.*<br>*The fact that in many countries the informal economy does not pay taxes, the question is how can they be integrated into it?* | Motivation for this could be the extensive literature on tax avoidance. However, carbon pricing on fuels is hard to avoid as they are difficult to hide (unlike income in the case of income taxes). Hence a shift from labor to carbon taxes might result in less tax avoidance or higher tax revenue (Macho-Stadler 2008). |
| Policy implementation | *What are possibilities for heterogeneous carbon prices between countries?*<br>*Combination of quantitative and qualitative studies to analyse how carbon pricing works together with regulatory instruments and informational instruments*<br>*Correct level of border of adjustments and interactions with other policies*<br>*How to build pro-carbon pricing coalitions* | Temporarily, as a transition mode, since over a long time would allow too much carbon leakage.<br>There is some literature already on this (see the review by van den Bergh *et al* 2021), but some instrument combinations merit more attention.<br>Several researchers (e.g. Nordhaus 2015, Sprinz *et al* 2018) addressed the topic of a carbon/climate club, on how to build up a stable coalition and protect or expand it using border adjustment tariffs. |

realistic models of carbon pricing (3T6). Those who rank carbon tax but not cap-and-trade above average want to study regulation of emissions at the source (3T3), long terms effects of the policy (3T2) and how it works with other policy instruments (3T2). Those who are relatively more in favor of cap-and-trade—how to apply differentiated carbon price for different sectors (3T1). And those who dislike both instruments in a policy mix—public understanding (3T4), global equitable implementation (3T5) and political acceptability (3T7).

The topics of identified research gaps can be considered as themes that should be given priority. The very nature of the topic modeling analysis, however, may not allow for identifying specific innovative research suggestions, as rare terms to characterize a novel research topic are typically filtered out at the data preparation stage. To complement the STM results, we identify here additional research suggestions based on our judgment as researchers with considerable experience in the field. We proceeded as follows: two authors independently screened the responses and the third assessing the result of this.

Scrutinizing the responses, we found that several respondents indicate that there are no research gaps on the topic of carbon pricing, while a few others admit they know little about carbon pricing or its literature and hence conclude they are uncapable of suggesting relevant ideas for future research. Many responses provide overly general suggestions about themes that already have received a lot of attention, such as public support, distributional effects, carbon leakage, impact on developing countries, or adequate models for impact assessment. Another group of respondents suggests original but irrelevant topics, because unrelated to carbon pricing; many of these seem to be motivated by own research interests. Again, other respondents make opinion statements rather than formulating research topics or questions. It is also noteworthy that various responses reflect a limited understanding of carbon pricing, such as that it will only affect the energy sector.

After cleaning for the above responses, rather few concrete suggestions for genuinely novel research remain. Table 4 collects the most interesting suggestions, which fall apart in three categories, namely policy impact, acceptability and implementation (first column). The final column of table provides some nuances about, and ideas for tackling, the respective research suggestion.

## 6. Conclusions and policy implications

To assess scientific opinion on carbon pricing, we undertook computational-linguistic analysis of responses to three open-ended questions in a global survey. This covered researchers from various research fields who published on climate policy in academic journals and have many years of experience. The questions asked about strengths and weaknesses of carbon pricing and themes meriting further research.

As main perceived strengths of carbon pricing compared with other policy instruments, we identified seven topics: investment incentive; clear price signal; effectiveness; makes polluter pay; encourages abatement; decentralizes policy; and is efficient. It is interesting to note that while many of these strengths resonate with the literature, it also shows that some arguments—like the capacity of carbon

pricing to limit energy/carbon rebound (van den Bergh 2011, Font Vivanco *et al* 2016, Freire-González 2020)—do not emerge prominently. As main perceived weaknesses respondents mention: households are affected; the policy is vulnerable to manipulation; it can increase inequality; may be politically infeasible; has low public support; and is difficult to implement globally. Especially the topic on amenability to manipulation is interesting since the literature addressing this issue is scarce (Frunza 2013, Stavins 2022).

We have discussed that some of the assessed perceptions and opinions are not in line with received insights from the theoretical and empirical literature on carbon pricing. This suggests that more communication about climate policy and carbon pricing is needed between academic researchers from distinct disciplines. This is also confirmed by our assessment of perceived research gaps, which include many suggestions that are overly general or that have already received considerable attention. Main topics stressed by the researchers focus on the need to improve public understanding of carbon pricing, its political acceptability, its synergies with other policies, its long-term effects, and how it can be implemented in an equitable way in developing countries and worldwide.

In addition to the quantitative analysis by the topic modeling method, we manually screened all responses regarding suggestions for future research, identifying specific propositions, such as formation of a climate coalition and determination of an effective border adjustment tariff (as examples of the topic of 'global and equitable implementation') and how different stakeholders—firms, labor unions, fossil fuel companies—affect actual policy implementation (as examples of the topic of 'political acceptability of the policy'). We classified these ideas in three categories, namely policy impact (e.g. impact and feasibility of very high carbon prices on inflation, preferences, non-rational behavior and rich people), acceptability (e.g. communicating benefits of carbon pricing to conservative or neoliberal voters and politicians, voter preferences about carbon prices vs bans, and distribution impacts beyond income), and implementation (e.g. role of multinational companies and informal economy, potential for heterogeneous carbon prices between countries, and synergy with other instruments). We further conducted statistical analysis identifying significant correlations between topic prevalence in the responses of researchers and the disciplines the scholars are active in, their gender, experience and support of a carbon tax and cap-and-trade in a policy mix. For example, younger researchers are more likely to talk about possible manipulation of carbon pricing and difficulty to implement it globally, while more experienced researchers suggest developing more realistic and data-driven models of carbon pricing. Understanding these generational and interdisciplinary differences between researchers is important if our aim is to stimulate more communication in the community and attempt to reach more consensus about desirable climate policy.

All in all, our results provide insight into how researchers from different disciplines think about climate policy in general and carbon pricing in particular. We find some misalignment in knowledge across disciplines which suggests the need for more exchange of arguments and evidence to assure more consistency regarding advice for society and politics. In addition, we noted gaps between researchers from wealthier and poorer countries, which may be explained by carbon pricing having been implemented and studied mostly in richer countries, while possibly usefulness of and barriers to carbon pricing may be perceived also differently due to local experiences. We commented on these various suggestions, indicating that some are more urgent and relevant in our view than others. We hope that some of the identified and synthesized future research avenues are considered useful for further exploration. In addition, further surveys could be undertaken with a more specific focus, for example, involving researchers from a narrower but deeper area of expertise as compared to our broad sample of general expertise.

## Data availability statement

The data that support the findings of this study are openly available at the following URL: https://github.com/IvanVSavin/GlobalScientistsSurvey.

## Acknowledgments

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## Conflict of interest

Authors declare no conflict of interests.

## 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.

# Appendix A. Additional results and discussion

**Table A1.** Respondent characteristics and general attitudes.

| Characteristic | Mean or *n* |
|---|---|
| Research fields | Agriculture/forestry ($n = 25$), ecological economics ($n = 29$), engineering ($n = 83$), environmental economics ($n = 164$), geography ($n = 42$), industrial ecology ($n = 12$), law ($n = 10$), mathematics & computer science ($n = 11$), natural sciences ($n = 111$), other environmental social sciences ($n = 43$), other economics ($n = 67$), political science ($n = 87$), psychology ($n = 11$), sociology ($n = 13$), sustainability transition studies ($n = 81$) |
| Years of research experience | 18.5 |
| Gender (1 = female, 2 = men) | 1.7 |
| Continent of residence | African countries ($n = 33$), Asia ($n = 126$), Europe ($n = 444$), North America ($n = 126$), Oceania ($n = 34$), South America ($n = 24$), see also figure A1 |

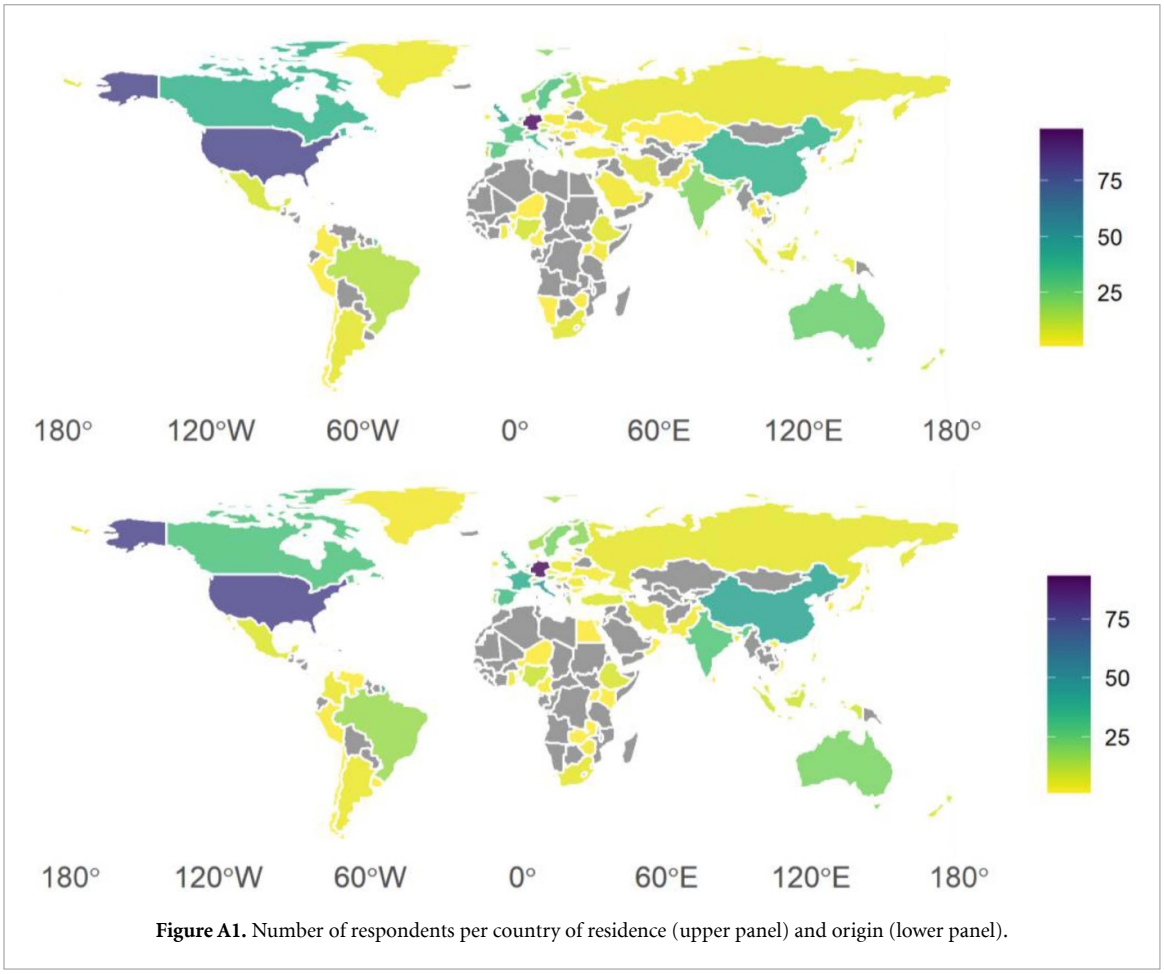



**Figure A1.** Number of respondents per country of residence (upper panel) and origin (lower panel).

As we demonstrate in figure A3, we did not find strong correlations between any pair of covariates included in each of the two topic models. The only exception was the rating of carbon taxation and cap-and-trade in the policy mix (Pearson correlation equals 0.43). The variance inflation factor (VIF), which measures how much the variance of a regression coefficient is inflated due to multicollinearity, ranges between 1.05 and 1.32 for the two models. These values are much lower than the conservative benchmark of 5, suggesting absence of multicollinearity in our regression analysis.

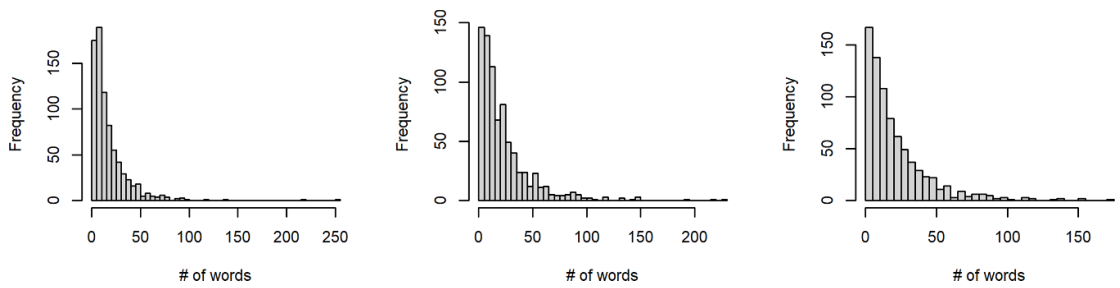



**Figure A2.** Length of responses to the three open-ended questions (first question in the left plot, second in the middle and the third in the right one).
*Note:* on the *X*-axis the shortest length of response is 1 word.

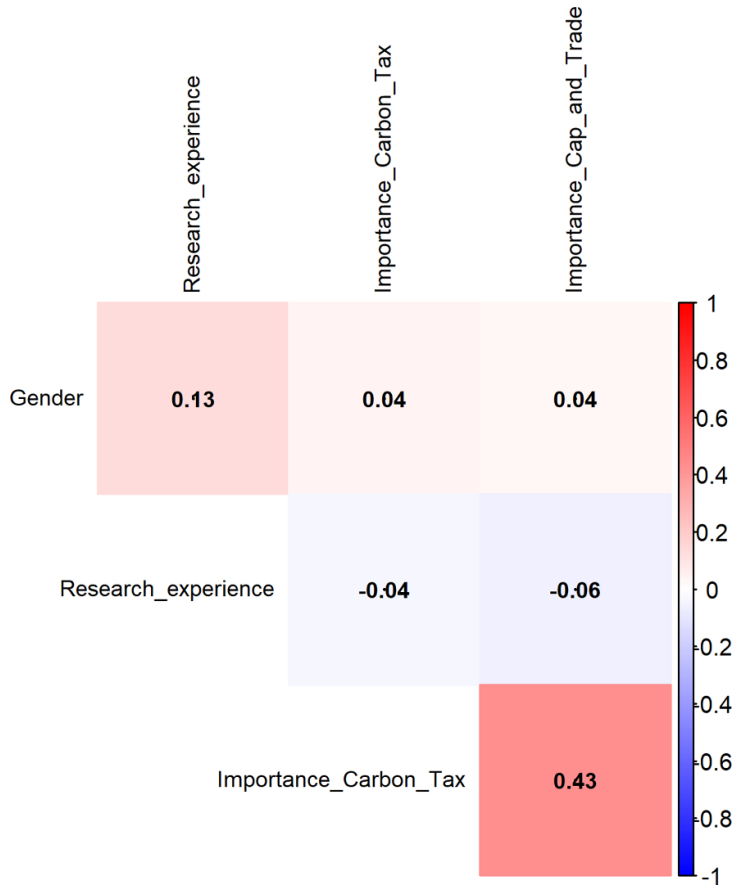



**Figure A3.** Testing pairwise correlations among covariates in our STM models.
*Note:* none of the correlations is significant at 10% level or better.

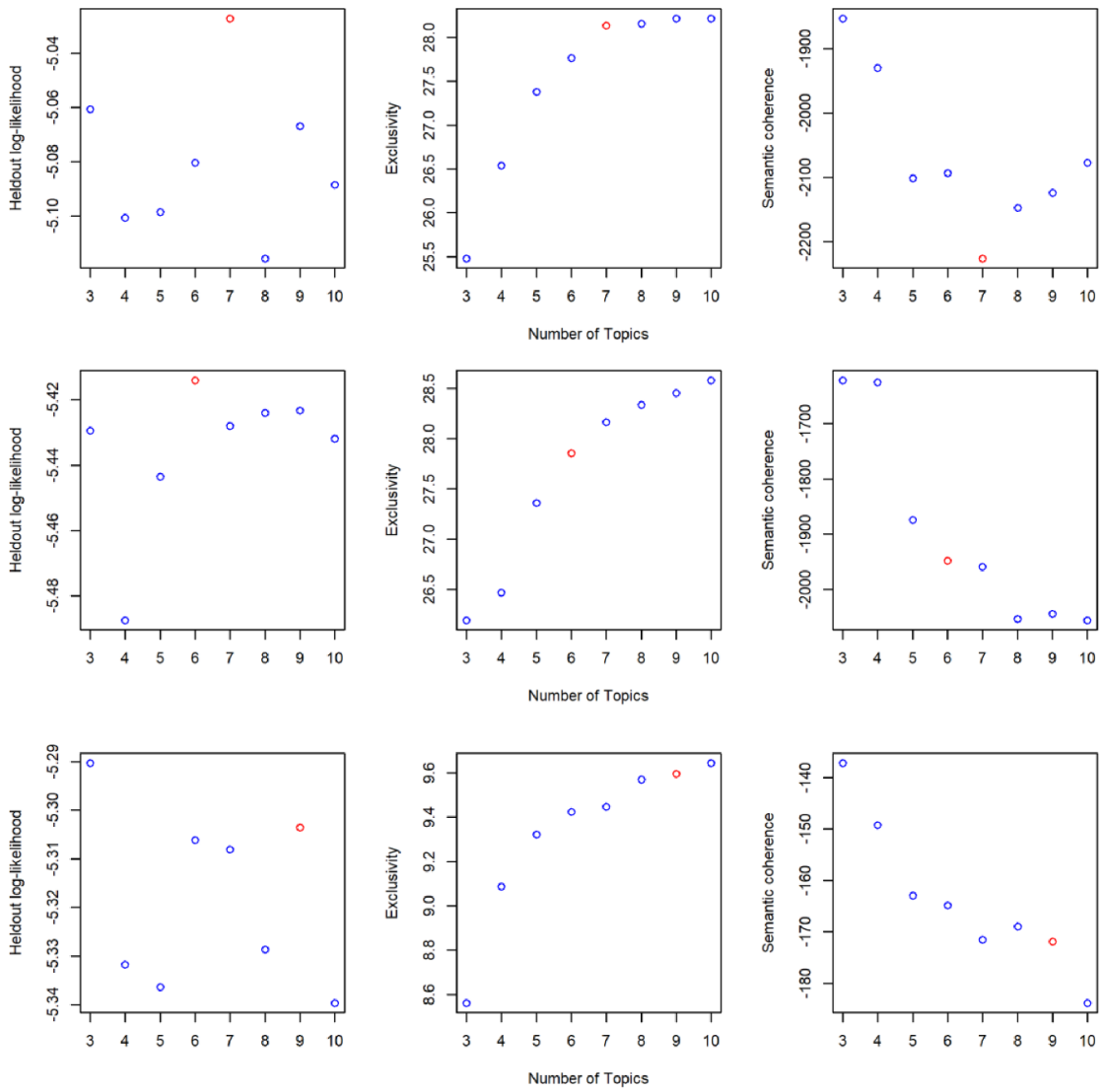



**Figure A4.** Model performance for distinct number of topics for the first (top panel), the second (middle) and the third (lower panel) open-ended questions.


**Figure A5.** Co-occurrence of topics for the first open-ended question.

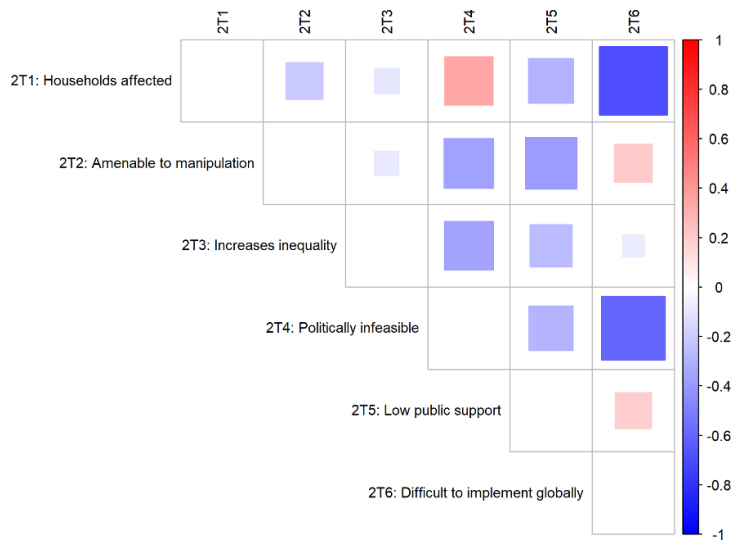



**Figure A6.** Co-occurrence of topics for the second open-ended question.

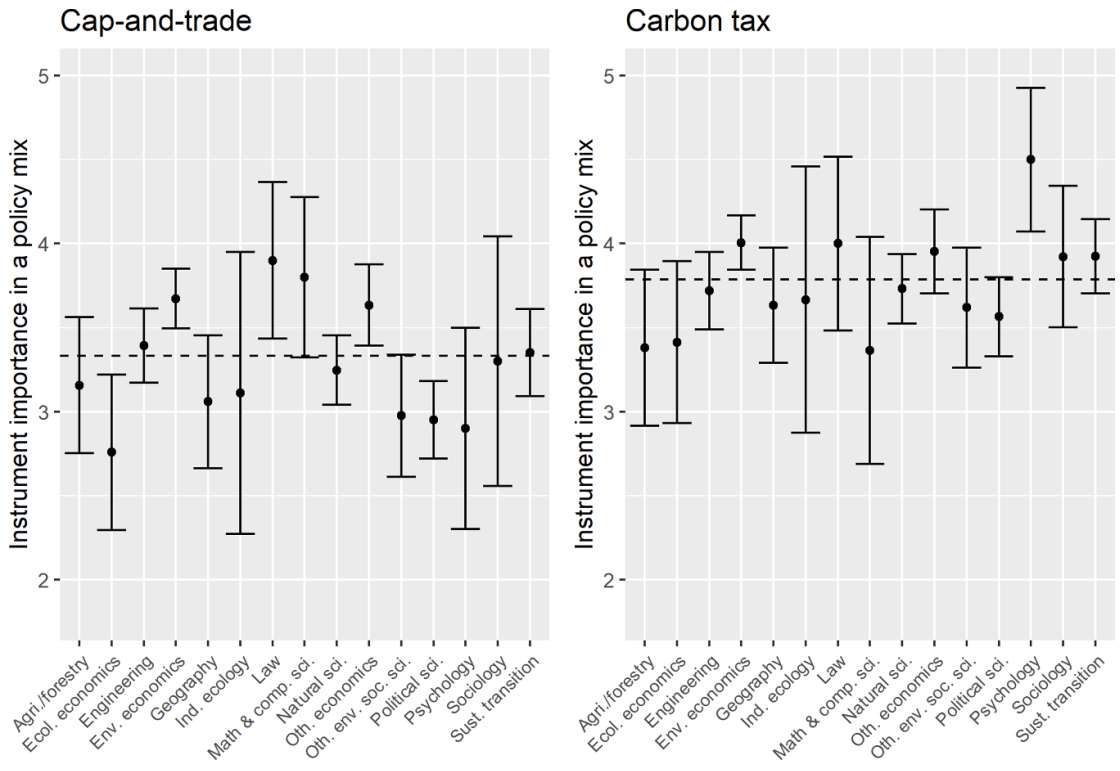



**Figure A7.** Rated importance of the two carbon pricing instruments. The scale on the $Y$-axis ranges from 1 = rated as unimportant to 5 = rated as extremely important. Data points represent mean values and error bars +/− 2 s.e. The dashed lines indicate average importance.

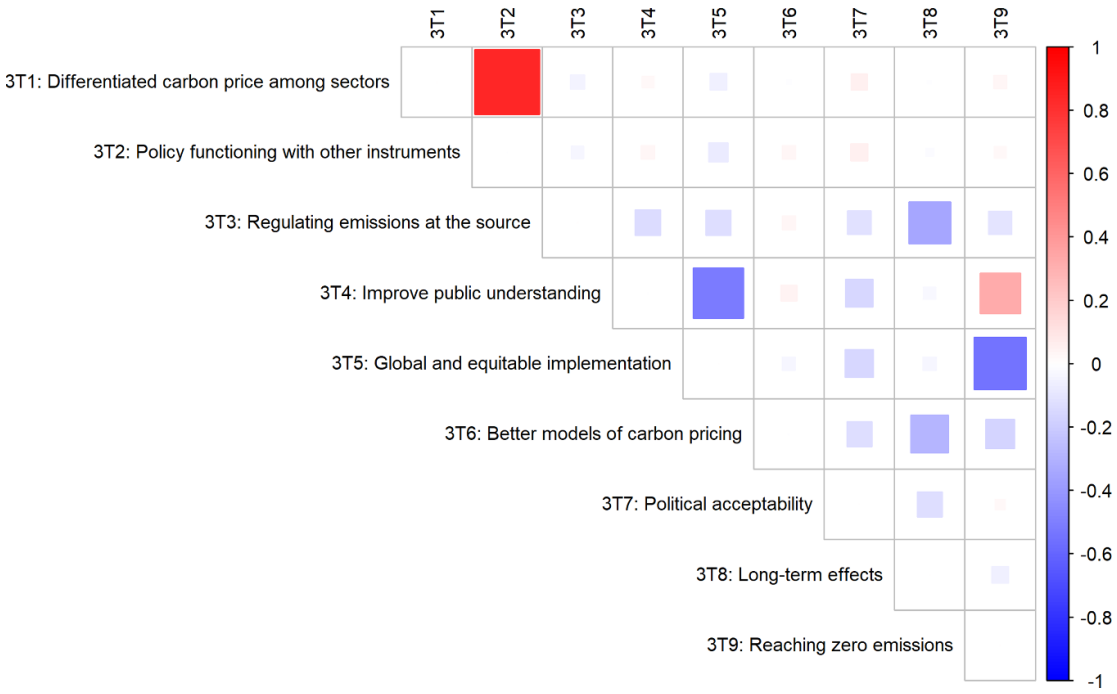



**Figure A8.** Co-occurrence of topics for the third open-ended question.

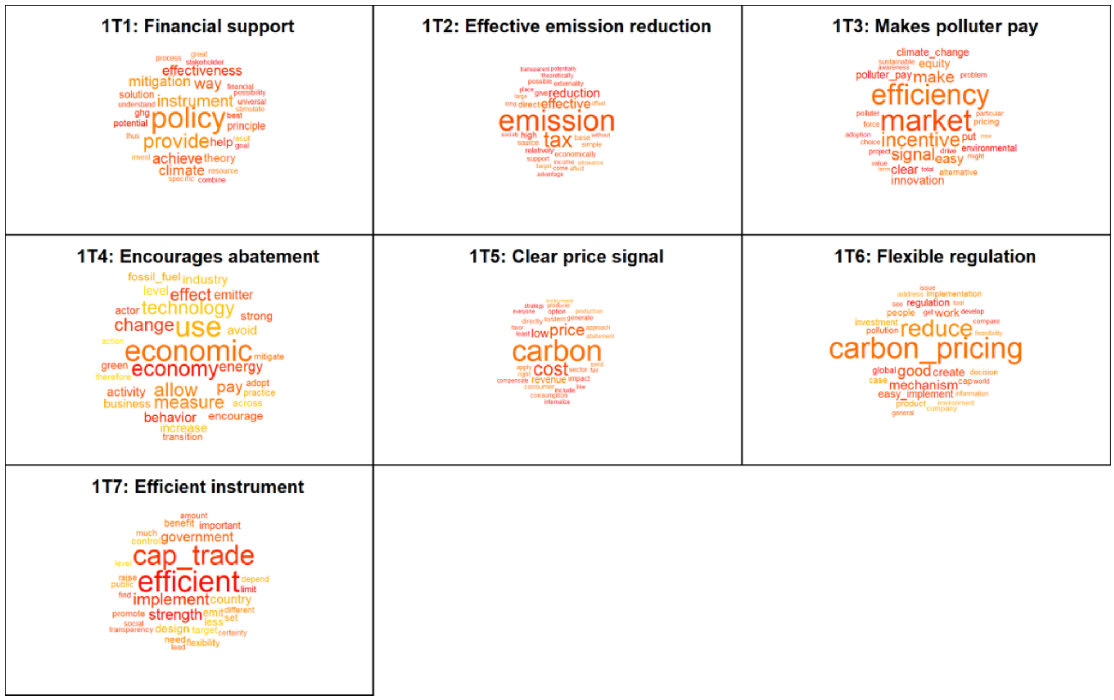



**Figure A9.** Word clouds of seven topics generated from the first open-ended question on perceived strengths of carbon pricing. *Note:* the font size reflects the probability (weight) of the respective word given the topic, while darker color of the word indicates its higher exclusivity.

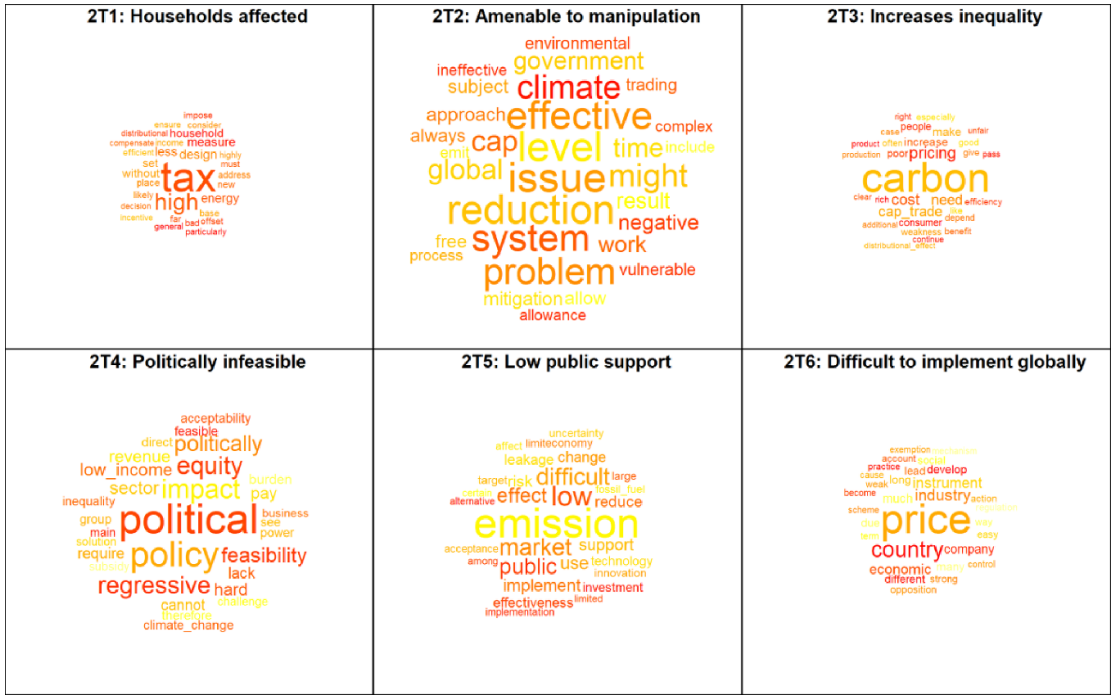



**Figure A10.** Word clouds of six topics generated from the second open-ended question on perceived weaknesses of carbon pricing.
*Note:* The font size reflects the probability (weight) of the respective word given the topic, while darker color of the word indicates its higher exclusivity.

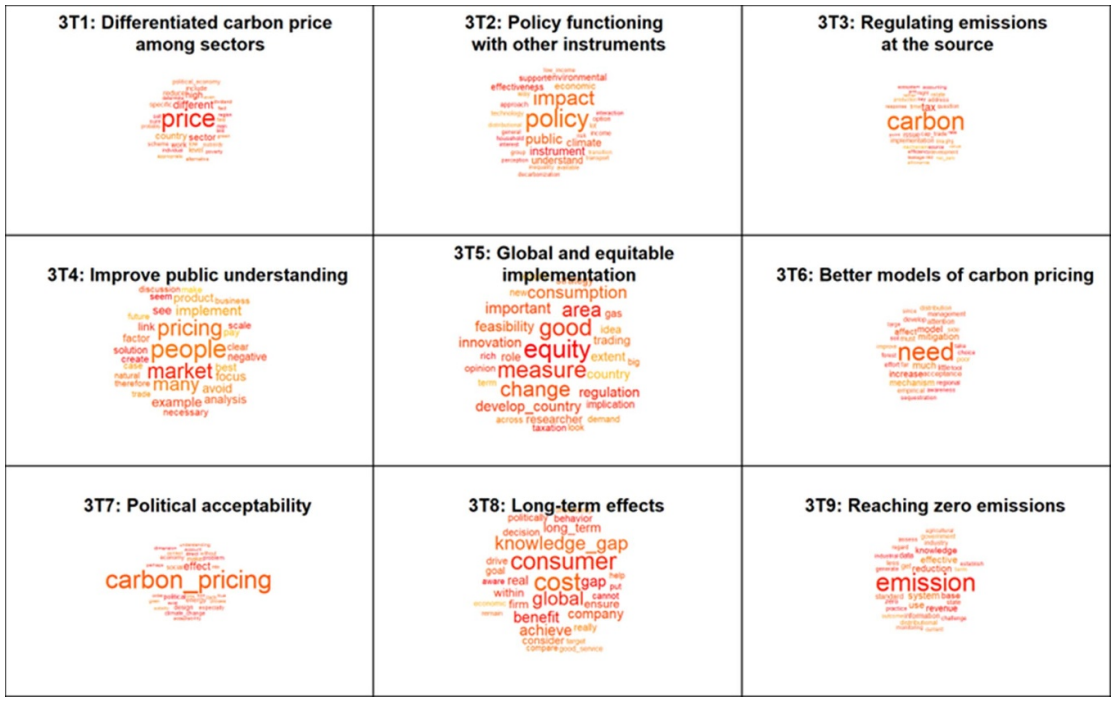



**Figure A11.** Word clouds of six topics generated from the third open-ended question on perceived knowledge gaps about carbon pricing.
*Note:* the font size reflects the probability (weight) of the respective word given the topic, while darker color of the word indicates its higher exclusivity.

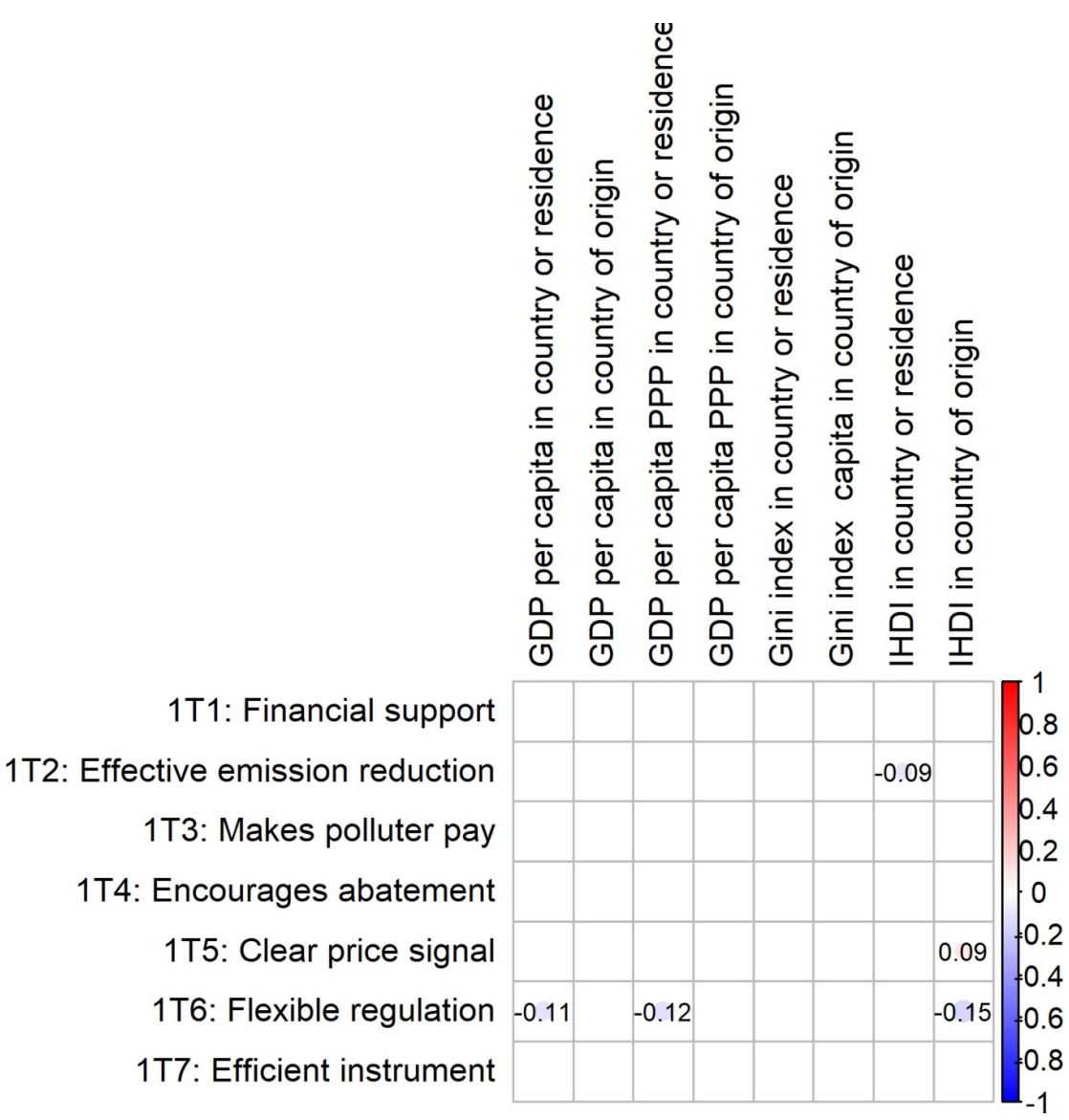



**Figure A12.** Pearson correlation between the prevalence of topics on perceived strengths of carbon pricing in the responses and the socio-economic indicators for the country of residence and origin of the researchers.
*Note:* only results significant at the 5% significance level are reported.

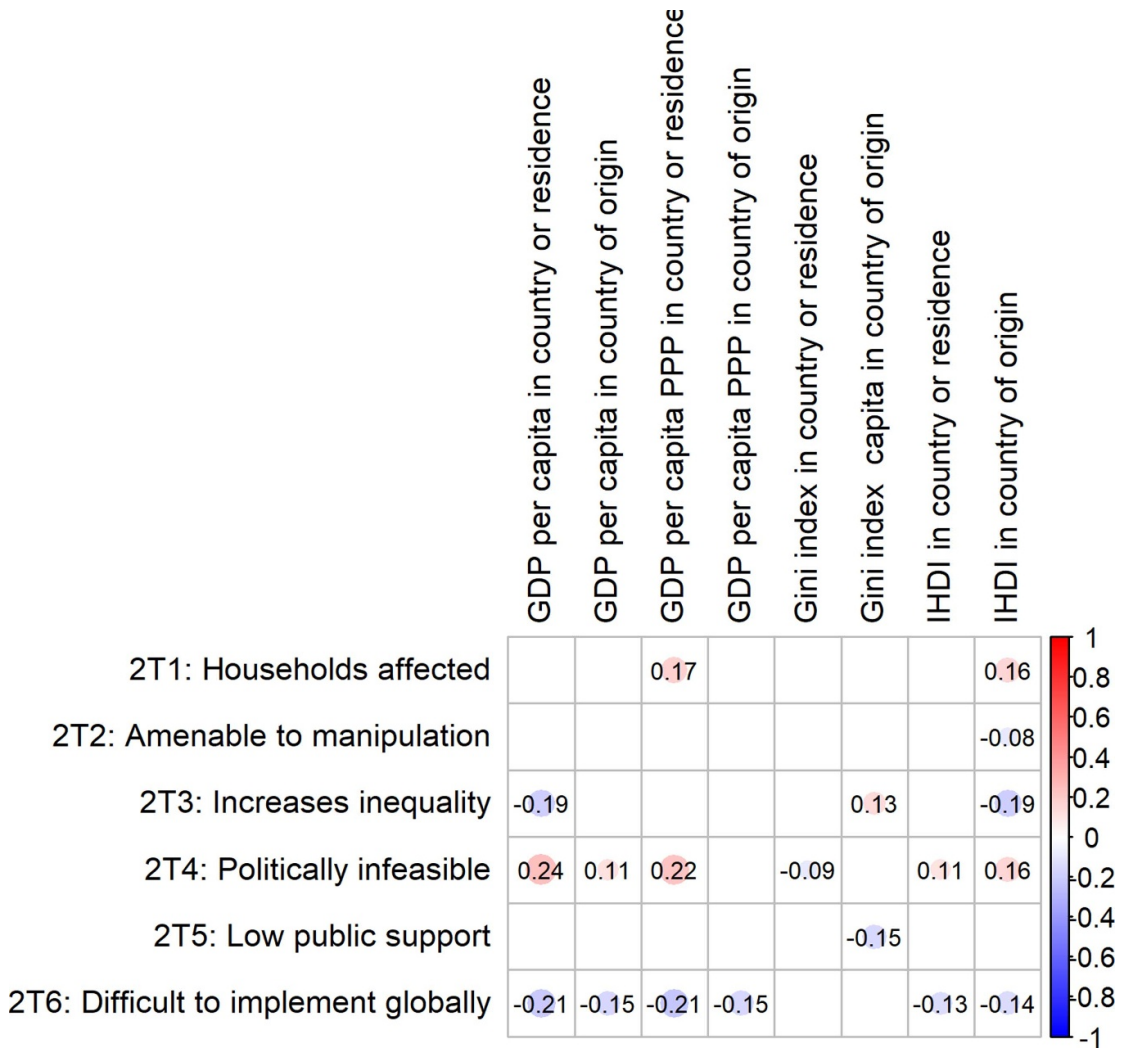



**Figure A13.** Pearson correlation between the prevalence of topics on perceived weaknesses of carbon pricing in the responses and the socio-economic indicators for the country of residence and origin of the researchers.
*Note:* only results significant at the 5% significance level are reported.

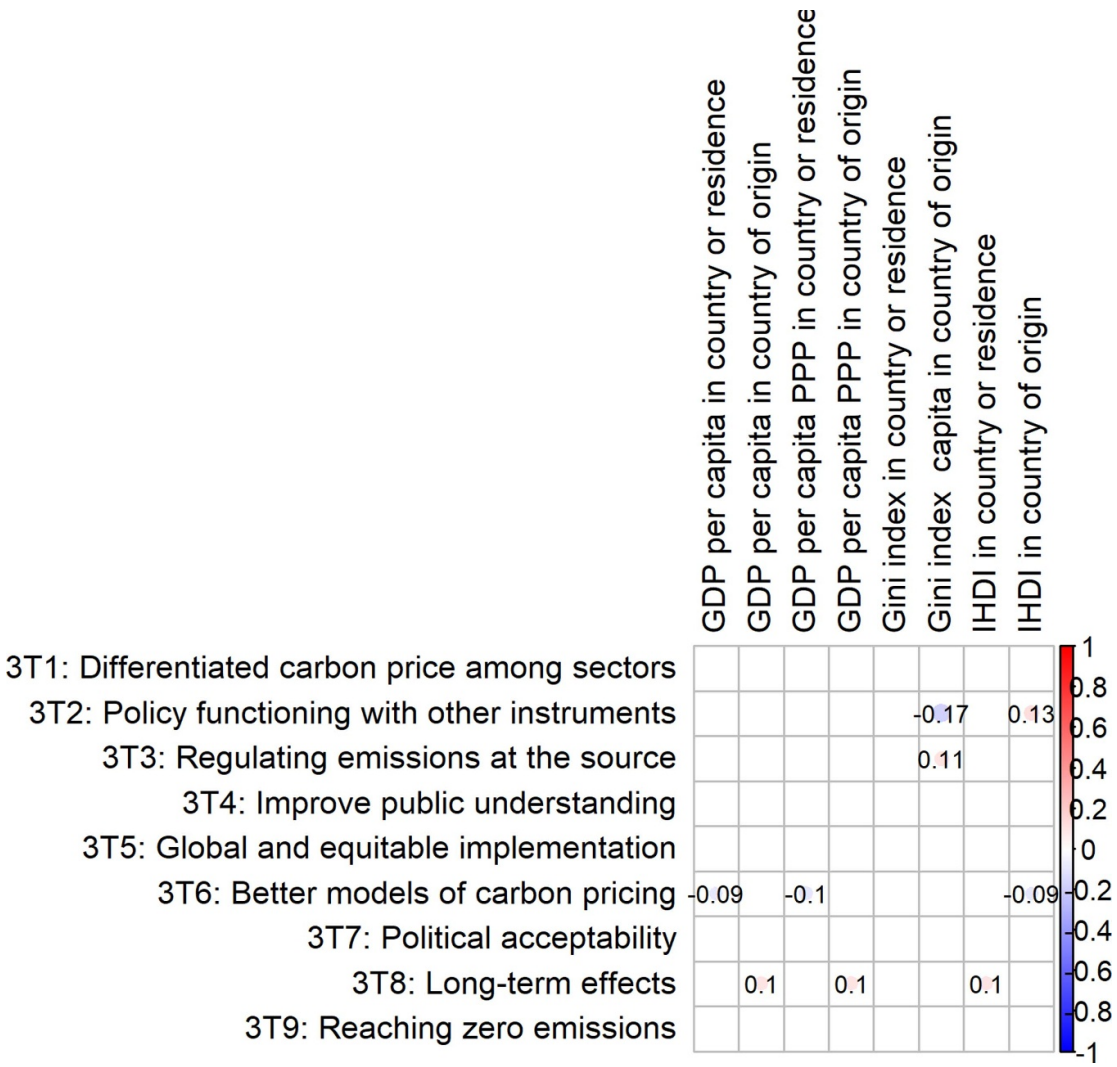



**Figure A14.** Pearson correlation between the prevalence of topics on perceived knowledge gaps of carbon pricing in the responses and the socio-economic indicators for the country of residence and origin of the researchers.
*Note:* only results significant at the 5% significance level are reported.

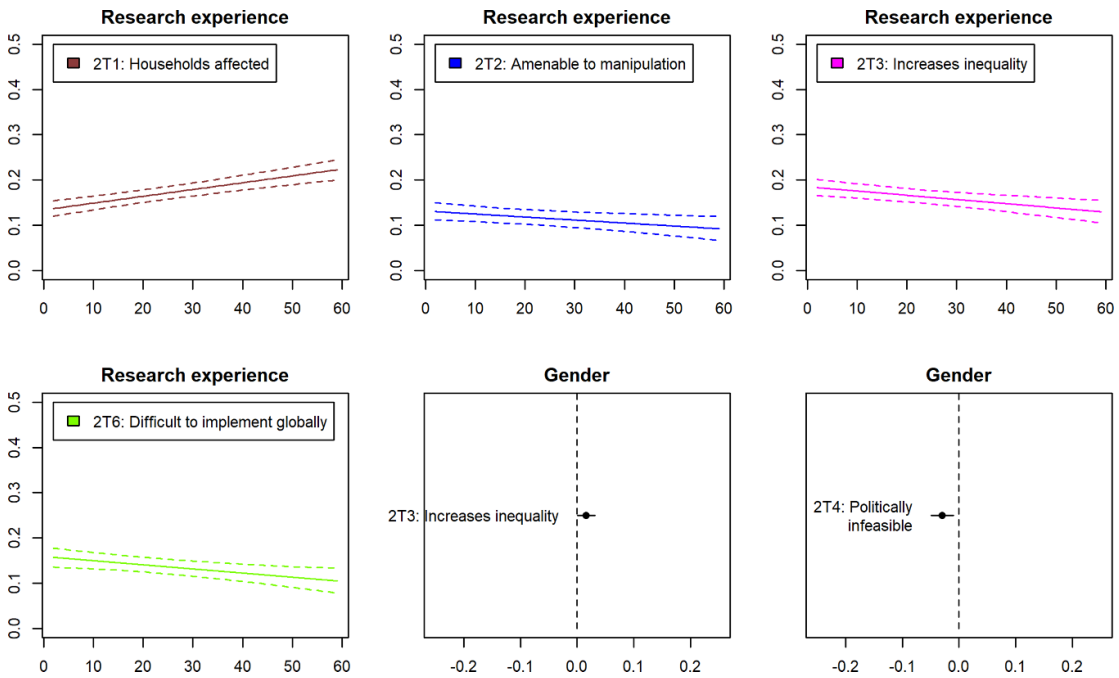



**Figure A15.** Effect of covariates on topic prevalence for perceived weaknesses of carbon pricing.
*Note:* coefficients generated by a regression where the outcome variable is the topic prevalence in each response. Point estimates of selected covariates on topic prevalence are plotted holding all other covariates constant. The plots for research experience shows the number of years of research experience on the horizontal axis. The plot for gender shows mean difference in topic proportions between male and female (a positive value on the horizontal axis indicates a larger prevalence for male respondents). Only results significant at least at the 5% level are displayed.

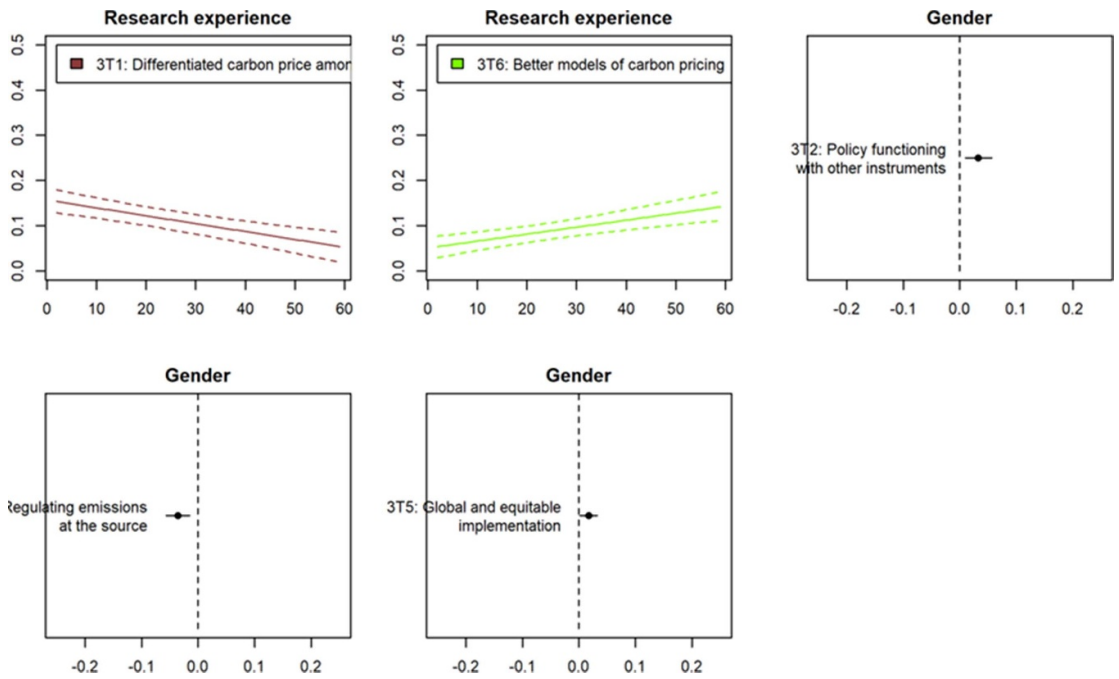



**Figure A16.** Effect of covariates on topic prevalence for perceived knowledge gaps about carbon pricing.
*Note:* coefficients generated by a regression where the outcome variable is the topic prevalence in each response. Point estimates of selected covariates on topic prevalence are plotted holding all other covariates constant. The plots for research experience shows the number of years of research experience on the horizontal axis. The plots for gender show mean differences in topic proportions between male and female (a positive value on the horizontal axis indicates a larger prevalence for male respondents). Only results significant at least at the 5% level are displayed.

**Table A2.** Results of the regression analysis for the STM model based on the first open-ended question on perceived strengths.

| | Intercept | Agriculture/ forestry | Ecological economics | Engineering | Geography | Industrial ecology | Law | Mathematics & computer science | Natural sciences | Other economics | Other environmental social sciences | Political science | Psychology | Sociology | Sustainability transition studies | Gender | Research experience | Importance carbon tax | Importance cap-and-trade |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1T1 | −0.134*** | | | | | | | | | | | | | | −0.040*** | | | −0.011*** | 0.008** |
| 1T2 | 0.162*** | | −0.029* | −0.024* | | | | | −0.023* | | −0.031** | −0.022* | | 0.055* | | | | 0.007** | −0.012*** |
| 1T3 | 0.126*** | | −0.03* | | | | | | | | | | | | | | | | |
| 1T4 | 0.075*** | | 0.066** | 0.098*** | 0.068*** | | | | 0.048*** | | 0.051** | | 0.164*** | | 0.105*** | | −0.001** | 0.016*** | |
| 1T5 | 0.224*** | | | | −0.045** | | | | | | | −0.032** | | | | −0.033*** | | 0.023*** | −0.021*** |
| 1T6 | 0.127*** | | | | | | | | | | | | | | −0.040*** | | | −0.015*** | 0.011*** |
| 1T7 | 0.153*** | | | −0.028* | | | | | | | | | | | −0.049*** | | | −0.018*** | 0.008* |

*Note:* Asterisks ***, **, and * denote 1%, 5%, and 10% significance, respectively. Coefficients indicate whether prevalence of respective topics changes with the value of the covariates. Only coefficients significant at least at 10% level are shown. Environmental economics is the benchmark group.

**Table A3.** Results of the regression analysis for the STM model based on the second open-ended question on perceived weaknesses.

| | Intercept | Agriculture/ forestry | Ecological economics | Engineering | Geography | Industrial ecology | Law | Mathematics & computer science | Natural sciences | Other economics | Other environmental social sciences | Political science | Psychology | Sociology | Sustainability transition studies | Gender | Research experience | Important carbon tax | Importance cap-and-trade |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2T1 | 0.165*** | −0.055*** | | −0.061*** | | −0.044*** | | −0.072*** | −0.069*** | −0.022* | −0.0086*** | | −0.047** | | −0.035*** | | | | −0.004* |
| 2T2 | 0.177*** | | | 0.025* | | | | | 0.027** | | 0.078*** | | | | 0.035*** | | −0.001** | −0.006* | −0.009*** |
| 2T3 | 0.244*** | | | 0.035*** | 0.061*** | | 0.057* | | 0.091*** | 0.081*** | | | 0.061* | | | −0.016** | −0.001*** | | |
| 2T4 | 0.109*** | | −0.051** | −0.050** | | | −0.080** | | −0.073*** | | −0.075*** | | | | −0.038** | 0.029*** | 0.001* | | |
| 2T5 | 0.150*** | | | | | | −0.099*** | | −0.031** | | | | | | | | | 0.008* | |
| 2T6 | 0.154*** | 0.001* | | 0.058*** | | | | | 0.055*** | −0.025* | 0.105*** | | | | 0.041*** | | −0.001*** | | 0.012*** |

*Note:* Asterisks ***, **, and * denote 1%, 5%, and 10% significance, respectively. Coefficients indicate whether prevalence of respective topics changes with the value of the covariates. Only coefficients significant at least at 10% level are shown. Environmental economics is the benchmark group.

**Table A4.** Results of the regression analysis for the STM model based on the third open-ended question on perceived research gaps.

| | Intercept | Agriculture/ forestry | Ecological economics | Engineering | Geography | Industrial ecology | Law | Mathematics & computer science | Natural sciences | Other economics | Other environmental social sciences | Political science | Psychology | Sociology | Sustainability transition studies | Gender | Research experience | Important carbon tax | Importance cap-and-trade |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3T1 | 0.195*** | | | | −0.056*** | | | | | | | | | | | | −0.002*** | −0.010** | |
| 3T2 | 0.188*** | | | | | | | | −0.039*** | 0.038* | | 0.052*** | | | | −0.032*** | −0.001* | | |
| 3T3 | 0.077** | | | −0.059*** | −0.059** | | | | | −0.038** | −0.087*** | −0.073*** | | | −0.042** | 0.036*** | | 0.022*** | −0.017*** |
| 3T4 | 0.153*** | | | | | | | | 0.027** | | | | | | | | | −0.016*** | |
| 3T5 | 0.164*** | −0.038* | | | | −0.087*** | −0.095*** | | −0.029** | | 0.035** | | | −0.087*** | 0.030** | −0.017** | | −0.007** | |
| 3T6 | 0.465* | | | | 0.048** | | | | 0.042*** | 0.032* | | | | | | | 0.002*** | | |
| 3T7 | 0.124*** | | | | 0.054** | | | −0.059** | −0.021* | | | 0.033*** | | | | 0.014* | 0.001* | −0.009*** | |
| 3T8 | 0.034* | | | 0.044*** | | | | | 0.036*** | | 0.067*** | | 0.062* | −0.049** | | | | 0.010*** | |
| 3T9 | | | | | | | | | | −0.043** | −0.049** | | | 0.082* | −0.034** | | | | 0.017*** |

*Note:* Asterisks ***, **, and * denote 1%, 5%, and 10% significance, respectively. Coefficients indicate whether prevalence of respective topics changes with the value of the covariates. Only coefficients significant at least at 10% level are shown. Environmental economics is the benchmark group.

## Appendix B. The questionnaire

**Welcome**

The main purpose of this global expert survey is to obtain an overview of opinions regarding climate mitigation policies in different disciplines and to derive from this an interdisciplinary agenda for future research.

The questions are formulated in a way to allow researchers from a wide range of disciplines and countries to participate. The time to complete the survey is expected to be about 10 min.

The survey is part of a project funded by an Advanced Grant from the European Research Council (EVOCLIM, grant agreement 741 087, Autonomous University of Barcelona). The survey data will be used exclusively for academic research purposes. For further information about data protection issues, please click here.

Your responses will remain strictly confidential. If you have any questions, please contact climate.policy@uab.es.

Did you read the study description above and do you volunteer to take part in this survey?

- Yes
- No

**Additional information about data protection issues after using the 'click here' button**

You can withdraw from the study at any time without giving explanations and with no negative consequences. The information gathered will not be used for profiling purposes, will be kept on a secure server at the Autonomous University of Barcelona, and conserved the necessary time for fulfilling the research goals. In addition, according to the European General Data Protection Regulation you can request any additional information by contacting climatepolicy@uab.es, possibly using request forms available on the website of the university's Data Protection Office (hyperlink to: www.uab.cat/web/coneix-la-uab/itineraris/proteccio-de-dades/drets-de-les-persones-interessades-1345764799916.html). You can also contact the university's data protection officer (hyperlink to: proteccio.dades@uab.cat) or the Catalan Data Protection Authority (hyperlink to: https://apdcat.gencat.cat/ca/contacte).

Which of the following best describes your primary field of study?

| | | |
|---|---|---|
| Ecological economics | History | Political sciences |
| Environmental economics | Humanities | Psychology |
| Economics (other areas) | Law | Sociology |
| Engineering | Mathematics and computer sciences | Sustainability transition studies |
| Geography | Natural science (Atmospheric, Climate, etc.) | Other research |

What are your main research topics? Please mention one or more keywords separated by commas (e.g. agriculture, energy policy).

*[_____open text field_____]*

How important do you consider the following criteria for evaluating climate policy instruments?

(Response scale: 1 = unimportant; 2 = somewhat important; 3 = important; 4 = very important; 5 = extremely important)

- **Effectiveness**, i.e. certainty and degree of realization of the emissions-reduction objective
- **Efficiency**, i.e. achieving the objective at the lowest economic costs or welfare sacrifice
- **Equity**, i.e. avoiding regressive distributional effects
- **Feasibility**, i.e. taking into account public and political support for, and opposition to, a policy
- **Other**, please specify (optional): [_____*open text field*_____]

Here you can optionally add comments related to the question above: *[___open text field___]*

Can you please rate the following instruments of climate policy in terms of their performance on each of the four mentioned criteria? We are aware that this is a challenging task, so we are mainly interested in your expert intuition (or 'gut feeling').

(response scale: low, moderate, high)

| | Effectiveness (i.e. certainty and degree of realization of the emissions-reduction objective) | Efficiency (i.e. achieving the objective at the lowest economic costs or welfare sacrifice) | Equity (i.e. avoiding regressive distributional effects) | Feasibility (i.e. taking into account public and political support for, and opposition to, a policy) |
|---|---|---|---|---|
| Direct regulation (e.g. technical standards, quotas) | | | | |
| Carbon tax | | | | |
| Cap-and-trade | | | | |
| Adoption subsidies | | | | |
| Innovation support (e.g. R&D subsidies) | | | | |
| Information provision (e.g. education or ecolabels) | | | | |
| Other | | | | |

Here you can optionally add comments related to the question above: *[___open text field___]*

Overall, how important do you consider each of these instruments in the climate policy mix of a country?

(response scale: 1 = unimportant; 2 = somewhat important; 3 = important; 4 = very important; 5 = extremely important)

| |
|---|
| direct regulation (e.g., technical standards, quotas) |
| Carbon tax |
| Cap-and-trade |
| Adoption subsidies |
| Innovation support (e.g. R&D subsidies) |
| Information provision (e.g. education or ecolabels) |
| Other |

Here you can optionally add comments related to the question above: *[___open text field___]*

There is considerable debate about the specific role of carbon pricing (carbon tax or cap-and-trade) in the climate policy mix. What do you think are the main strength(s) and weakness(es) of carbon pricing compared with other instruments?

We would like that you take your time to answer this question and, if possible, write some sentences. All kinds of answers are welcome.

Strength(s): *[_____open text field_____]*

Weakness(es): *[_____open text field_____]*

Please indicate whether you agree or disagree with the following statements.

*(response scale: 1 = strongly disagree to 5 = strongly agree; do not know)*

(a) Since carbon pricing alters relative prices, firms and consumers automatically account for climate-change effects of their decisions.
(b) Carbon pricing has little impact on the speed of low-carbon innovation.
(c) Carbon pricing is the most effective instrument to limit energy/carbon rebound. An example of rebound is driving more kilometres after buying a more fuel-efficient car.
(d) Carbon pricing promotes emissions reduction at the margin but cannot stimulate major changes necessary for achieving zero carbon emissions.
(e) Carbon pricing decentralizes policy, thus reducing regulators' need for information.
(f) Contextual, sector-specific climate policies are more effective in terms of overall emissions reduction than economy-wide carbon pricing.
(g) Carbon pricing takes into account that in making purchasing decisions, most consumers are more influenced by prices than by environmental concerns.
(h) Carbon pricing can be more easily up-scaled and harmonized globally than other instruments.
(i) Carbon pricing functions worse than other instruments when consumers and firms do not make rational choices.
(j) A unique advantage of carbon pricing over other instruments is that it generates public revenues which can be used for multiple purposes.

Here you can optionally add comments related to the question above: *[___open text field___]*

Earlier you indicated that your primary field of study is: [display of response to Question 1].

To the best of your knowledge, what would you estimate is the percentage of researchers in your primary field of study who consider carbon pricing (tax or cap-and-trade) as very or extremely important component of a country's policy mix?

Please use the slider to choose a number from 0 (no one) to 100 (everyone): [___]

Do not know

Here you can optionally add comments related to the question above: *[___open text field___]*

Can you indicate knowledge gaps about carbon pricing that deserve attention in research?

We would like that you take your time to answer this question and, if possible, write some sentences. All kinds of answers are welcome.

*[_____open text field_____]*

How worried are you about climate change and its societal consequences?

(1 = not at all worried, 3 = a bit worried, 5 = somewhat worried, 7 = very worried, 9 = extremely worried, do not know)

Please indicate whether you agree or disagree with the following statements about economic (GDP) growth:

*(response scale: 1 = strongly disagree to 7 = strongly agree; do not know)*

Continued economic growth is essential for improving people's life satisfaction.

In view of limited natural resources, rich countries may have to give up their economic growth to assure that all poor people in the world can reach a fair standard of living.

Economic growth is necessary to finance environmental protection.

In the following, we just have a few more questions on your professional and personal background.

How many years have you been doing research? [____]

What gender do you identify with? Female | Male | Other

What is your country of residence? ____drop-down list of countries_____

What is your country of origin? ____drop-down list of countries_____

In politics people sometimes talk of 'left' and 'right'. Where would you place yourself on the following scale? 1 = left to 11 = right; do not know/prefer not to answer

Here you can optionally add comments related to the question above: *[___open text field___]*

Do you have any comments about this survey? *[_____open text field_____]*

If you wish to be informed about the results of this survey, please leave your email address below. The list of email addresses will be deleted once the results of the survey have been disseminated.

*[_____open text field_____]*

Thank you for your cooperation! Your response is very important to us.

## Appendix C. Email invitations

Dear colleague,

You have been identified as an expert in climate mitigation policy based on your publications related to this topic. Our objective is to elicit your views on a variety of climate policies to examine (dis)agreement across disciplines and to help guide future research efforts.

**We would be most grateful if you could respond to our (short) global expert survey accessible here:**

https://survey.cmix.com/6B0A628C/7E301C4Q/en-US

Please do not share this link with others.

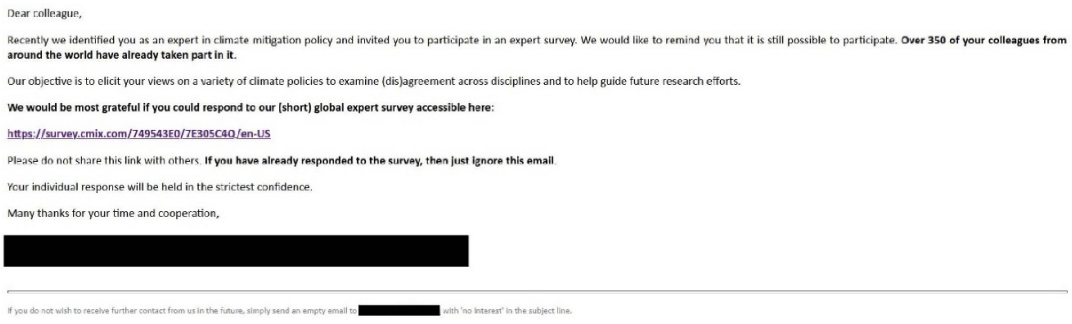
Your individual response will be held in the strictest confidence.

Many thanks for your time and cooperation,

[redacted]

If you do not wish to receive further contact from us in the future, simply reply to this email with 'no interest' in the subject line.

First reminder:



Dear colleague,

Recently we identified you as an expert in climate mitigation policy and invited you to participate in an expert survey. We would like to remind you that it is still possible to participate. **Over 350 of your colleagues from around the world have already taken part in it.**

Our objective is to elicit your views on a variety of climate policies to examine (dis)agreement across disciplines and to help guide future research efforts.

**We would be most grateful if you could respond to our (short) global expert survey accessible here:**

https://survey.cmix.com/749543E0/7E305C4Q/en-US

Please do not share this link with others. **If you have already responded to the survey, then just ignore this email.**

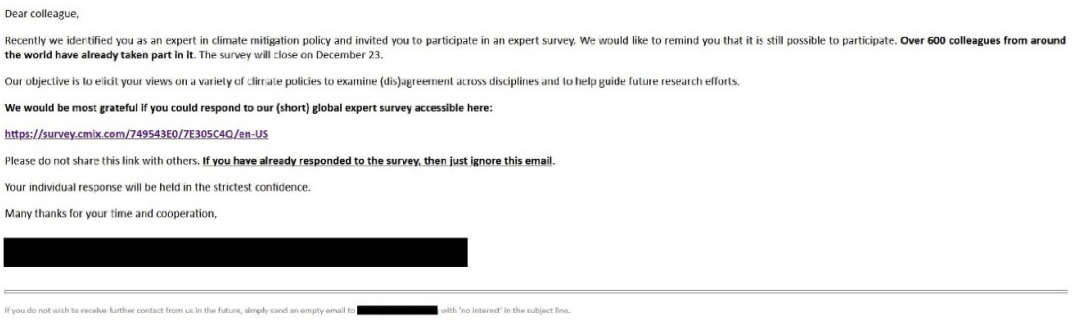
Your individual response will be held in the strictest confidence.

Many thanks for your time and cooperation,

[redacted]

If you do not wish to receive further contact from us in the future, simply send an empty email to [redacted] with 'no interest' in the subject line.

Second reminder:



Dear colleague,

Recently we identified you as an expert in climate mitigation policy and invited you to participate in an expert survey. We would like to remind you that it is still possible to participate. **Over 600 colleagues from around the world have already taken part in it.** The survey will close on December 23.

Our objective is to elicit your views on a variety of climate policies to examine (dis)agreement across disciplines and to help guide future research efforts.

**We would be most grateful if you could respond to our (short) global expert survey accessible here:**

https://survey.cmix.com/749543E0/7E305C4Q/en-US

Please do not share this link with others. **If you have already responded to the survey, then just ignore this email.**

Your individual response will be held in the strictest confidence.

Many thanks for your time and cooperation,

[redacted]

If you do not wish to receive further contact from us in the future, simply send an empty email to [redacted] with 'no interest' in the subject line.

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