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Boosting public support for climate policy through information provision: insights from German survey experiments

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Despite being an economists' favorite, carbon pricing suffers from limited public support, undermining the feasibility of target-consistent prices. Revenue rebating is frequently considered as a remedy. Across two experiments, we examine whether support rises when people receive (i) information about how carbon pricing and rebates work and (ii) personalized feedback on their carbon footprints and expected net monetary impact under carbon pricing with equal-per-capita rebates. Explaining how carbon pricing steers consumption and the administrative cost of rebates increase support. Most respondents hold inconsistent beliefs: they think their carbon footprint is below average but still expect to lose money after the rebate. Personalized feedback induces partial belief updating and increases support for carbon pricing among respondents who would actually gain, while support by net losers is not significantly affected. Our findings highlight the need for transparent, economics-based communication of climate policy.

Economists have long been advocating for carbon pricing as an efficient and scalable instrument of climate policy. By now, it has found its way into legislation in various constituencies, including the EU, Canada, several US states, China and Australia[1]. However, carbon prices remain at low levels and are partially offset by subsidies on carbon-intensive products[2]. While the global average carbon price amounted to USD 6 per ton of carbon in 2022, an estimated price of USD 75 would be required by 2030 if mitigation efforts are to succeed[3]. In Europe, where marginal abatement costs are already higher, carbon prices of up to EUR 275 in 2030 may be necessary to meet the EU's climate targets[4]. Again, this number is in stark contrast to the national carbon price on heating and transport fuels in Germany, which amounted to EUR 30 in 2022.

The political feasibility of the price increases required to reach the 2030 targets hinges on public support. Yet, the literature provides consistent evidence that public support for increasing carbon prices is limited[5–8]. In an attempt to bolster approval and mitigate the regressive distributional impact of carbon pricing, numerous constituencies either already implemented (e.g., Austria, Canada and Switzerland) or are currently considering rebating schemes (e.g., "climate money" in Germany, social climate fund at the EU level). Being relatively easy to implement, equal-per-capita (or lump-sum) rebates, refunding the same amount to each citizen, are frequently discussed as potential payout schemes. Lump-sum rebates appear to be both suitable for maintaining the emission-reducing incentive of carbon pricing and for alleviating the associated monetary burden, especially for low-income households[9,10]. Previous studies find that even though per-capita rebates to citizens can create some support for carbon pricing, respondents often prefer earmarking for green investments or subsidies[6,8,11–13].

Low support for carbon pricing may also stem from a lack of knowledge about the instrument. Respondents are typically unaware that carbon pricing is not merely a means of raising revenues for climate policy, but—first and foremost—is a climate policy instrument with a direct emission-abating effect[14]. Additionally, it has been verified in the lab that individuals tend to reject policies with direct costs and indirect benefits even when individual benefits outweigh costs, as may be the case for carbon pricing with subsequent rebates[15]. If rejection of the carbon price is driven by information deficits, providing information about the underlying mechanism and economic concepts (we will refer to this as "economic literacy" in the following) should increase support. However, previous studies call into question whether there is a link between knowledge about and support for carbon pricing[16,17]. While stark increases in the carbon price generally fail to garner public support[5,6], recent cross-national studies find that the carbon price gains popularity once respondents receive additional

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information about the policy[18–20]. Evidence from Germany indicates that the effect is highly contingent on the content of the treatment[21], with one study showing that even targeted information only increases support when addressing cost-related concerns, whereas fairness and effectiveness messaging have no positive impact[22]. Evidence from France[5] as well as Switzerland and the United States[23] reveals that informing respondents about whether they might benefit from a rebate increases support for carbon pricing, in the latter case even for large price increases. Our paper contributes to the existing literature on the effect of information provision by further exploring options for effective information treatments. Our focus is on identifying communication strategies which are easy to apply in practice (e.g., via letters) and equally effective among different groups of citizens. To that end, we conduct two separate survey experiments, (i) employing messaging of general knowledge about carbon pricing and revenue rebating and (ii) extending the approach of targeted information by providing reactive, personalized feedback based on respondents' previous answers regarding their carbon footprints. We both shed additional light on whether information treatments can increase public support for carbon pricing and examine to what extent personalized feedback can induce belief updating. Both experiments were conducted by a professional survey company with quota sampling along the dimensions of age, gender and place of residence on the aggregation level of federal states in summer and fall 2022 (detailed information on sample sizes and survey dates is available in the "Methods" section).

We contribute to the literature by identifying messages which increase support for carbon pricing. In particular, information about how carbon prices steer consumption to abate emissions and information about the administrative cost of rebating prove effective. Additionally, we show that enriching these messages with personalized feedback about expected net gains and costs after rebating revenues from carbon pricing, further increases public support.

Our first experiment consists of four information treatments explaining the economic concept of carbon pricing as well as costs and benefits associated with pricing and rebating. This experiment draws on readily available, general information. We provide incrementally more information with each treatment. All respondents are informed about the current level of the carbon price. The first treatment (T1.1) states that the German federal government plans to rebate revenues from carbon pricing on an equal-per-capita basis. This is enriched (T1.2) by an estimate of the average carbon price burden and the rebate in addition to explaining that individuals with a below-average carbon footprint will incur a monetary benefit from lump-sum rebates. The last two treatments combine this information with either (T1.3) disclosing the administrative cost of the rebate scheme or (T1.4) an explanation of how carbon pricing steers consumption away from high-carbon products to green alternatives regardless of how the government spends the associated revenues. We find significant and positive, yet small effects of providing more information on the acceptance of carbon pricing while the support for per-capita rebates remains unaffected. Consistent with a study conducted in 2020, before the introduction of the national emission pricing scheme[21], explaining the steering effect of carbon pricing remains effective at the time of our experiment, when households were already exposed to its impact on heating and transport fuels for 2 years as well as in the face of the 2022 energy price crisis. Providing information about the administrative cost has a comparable effect on support which, to the best of our knowledge, has not been examined before.

In the second experiment, we combine the information provided across all treatments T1.2 to T1.4 of the first survey into a single "full-information" treatment (T2.1). Treatment T1.1 is provided to the control group which is therefore slightly better informed than the control group in the first experiment. As the central novelty of Experiment 2, an additional treatment (T2.2) combines the full-information text with personalized feedback about the respondent's carbon footprint relative to the average consumer and whether they may expect monetary gains or losses from carbon pricing when combined with a per-capita rebate. Previous studies find that Canadian respondents incorrectly believe they will lose even after learning about the value of the rebate[24], while French respondents typically overestimate the burden imposed on them by carbon pricing[5]. We observe the same effects for respondents in Germany. Additionally, respondents in our sample severely underestimate their relative carbon footprints. Thus, respondents hold contradicting beliefs, as below-average emitters will mechanically incur a net monetary gain from equal-per-capita transfers. Compared to the French study, respondents are more willing to embrace positive personalized feedback and update their beliefs. Would-be winners become significantly more supportive of carbon pricing in general and even of higher prices while we find no negative effect on would-be losers.

Results

At the beginning of Experiment 1 before treatments were administered, 36% (sd: 0.48) of the respondents report that they had previously heard about the "climate money" rebate, almost twice as many (67%, sd: 0.47) had heard about the national carbon price on transport and heating fuels (see Supplementary Table 1). Only 31% of the respondents in the control group support carbon pricing (i.e., report a value of five or larger on the seven-point scale). As a descriptive indicator that our information treatments may be effective, the average post-treatment support for maintaining a positive carbon price across the entire sample is equal to 3.8, increasing from 3.4 in the control group to 4.1 in Treatment T1.4 which explains the consumption-steering effect of carbon prices (Supplementary Fig. 1). Support for a refund via the "climate money" remains virtually constant across all treatment groups at around 4.5 on average. Summary statistics for both experiments are provided in Supplementary Tables 1 and 2, respectively.

Effect of general information on support for climate policy

To identify the effect of the information treatments on the support for carbon pricing in general, an increase in the carbon price and the equal-per-capita rebate, we estimate the ordinary least squares (OLS) regression

$$Supp_i = \beta_0 + \sum_{j=1}^{4} \beta_i * T_{ij}, \quad (1)$$

whereby $Supp_i$ is respondent i's support for the respective policy instrument as measured on the continuous 7-point Likert scale (see section "Methods" for details) and T_{ij} denotes a dummy indicator which is equal to 1 if respondent i is administered treatment j. Since all treatments are randomly assigned (see Supplementary Tables 15 and 16), the model in (1) is estimated without additional socioeconomic controls.

The results are depicted in Fig. 1. We find small, yet significant and positive effects on support for maintaining the carbon price and even increasing the price level across all treatments except for the mini-treatment (T1.1). Simply stating that the government plans to rebate the revenues as in the mini-treatment is not sufficient to foster support. More informative treatments, explaining either how carbon pricing or the lump-sum rebate works are associated with larger point estimates β_i. Hence, providing additional information appears to be effective at increasing support. The significant and positive effect of information on revenue redistribution (T1.2) was not previously observed in other information treatment studies in Germany[21,22]. In contrast to these studies, we explicitly state that the average burden amounts to an annual EUR 120 and that below-average emitters will receive a rebate in excess of their costs. Supplementary Fig. 3 shows that the number of people who correctly state the average cost after the experiment increases strongly.

In contrast, we find no statistically significant effect of our treatments on support for the equal-per-capita rebate. This may be due to a number of factors. First, in comparison to carbon pricing, support for the rebate is high across the entire sample, averaging at 4.5, with only 23% of all respondents reporting a value below 4 (i.e., an at least slightly negative opinion). Second, previous studies find that respondents often prefer "green spending" or targeted transfers as a means of recycling carbon pricing revenues[6,8,11–13].

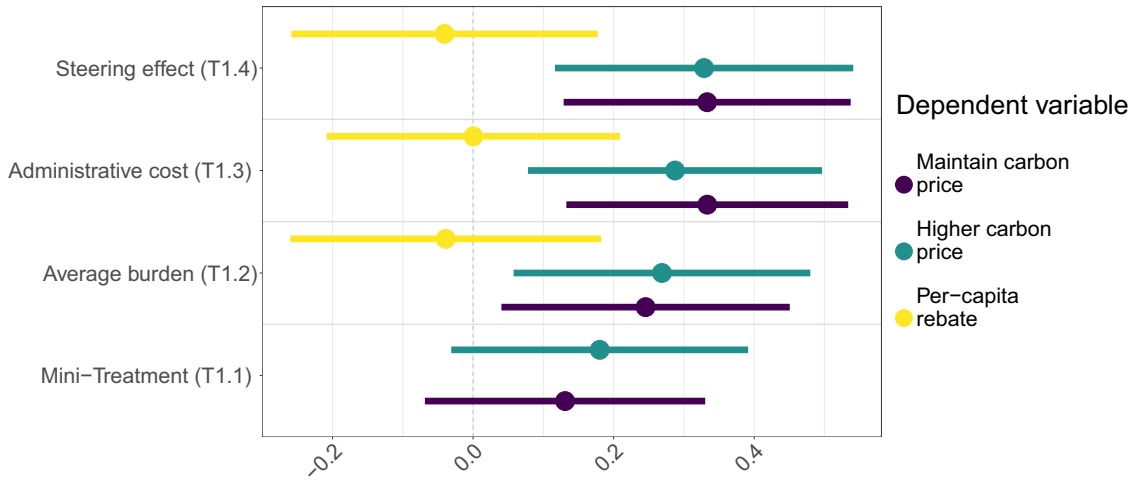


Fig. 1 | Support for carbon pricing and revenue rebating in Experiment 1. Notes: Regression of support for per-capita rebates and carbon pricing on the information treatments in Experiment 1. Horizontal bars represent the 95%-CIs. For full regression results, see Supplementary Table 3 and Supplementary Table 8 (including control variables). All dependent variables are z-scored. Since the control group is not questioned about the rebate, we use T1.1 as the reference group for supporting the rebate. Errors are heteroscedasticity robust standard errors. The dependent variables refer to the following items in the questionnaire: *Per-capita rebate*: The climate money should be introduced. *Maintain carbon price*: The carbon price should be maintained. *Higher carbon price*: The carbon price should be increased.

Therefore, our information treatments may not be able to alter this preference ranking such that respondents would still rather opt for green spending which is not on the menu in our experiment. Third, the models estimating support for carbon pricing and rebates are not immediately comparable as the latter employs the mini-treatment as its reference group. Since we do not inform the control group about the rebate, we also refrain from asking them about it. Re-leveling the model for carbon pricing to also rely on the mini-treatment as the reference category reduces the statistical significance of the treatment effects. However, we still observe significant effects of the "administrative cost" and "steering effect" treatments on support for maintaining the carbon price (see Supplementary Table 11). Fourth, informing that a rebate will refund the revenues from carbon pricing (at low administrative costs) which benefits below-average emitters may not be a strong enough treatment to induce higher support. In Section "Heterogeneous impact of personalized feedback", we will discuss in more detail that support for the rebate scheme may primarily depend on the anticipation to be over-compensated, i.e., driven by self-interest.

Effect of general information on subjective knowledge

Climate policy communication can also aim to improve citizens' understanding of how carbon pricing and rebates work. To assess the effectiveness of our information treatments in that regard, we elicit respondents' subjective post-treatment knowledge in Experiment 1. The results from an OLS regression are reported in Fig. 2. None of our treatments has a statistically significant effect on the subjective knowledge about carbon pricing. In contrast, subjective knowledge about the per-capita rebate is significantly improved by the administrative cost treatment (T1.3) which is specifically tailored to provide very tangible information about the rebate. This effect is robust to the inclusion of socioeconomic control variables if we account for partly heterogeneous treatment effects based on gender. Additionally, the "steering effect" treatment becomes significant for knowledge about the rebate at the 5% level. In line with the literature[25], we find that men report a higher level of subjective knowledge on average cannibalizing the treatment effect on them.

These results could be interpreted in a number of ways. First, it is possible that our treatments are too weak to induce a change in subjective knowledge. Both our results regarding the treatment effect on self-reported knowledge and the literature[16,17] cast doubt on whether we actually observe increased knowledge. Yet, as also shown in separate studies[18,21,22], additional information can improve respondents' support for both carbon taxes and redistribution. Thus, even though the treatments may not (or only to a limited extent) increase factual knowledge, they change how the respective policy instrument is perceived[26]. Second, carbon pricing and its economic impact may be difficult to comprehend. Despite already nudging respondents to express higher support for carbon pricing, they might need yet more information to confidently report good knowledge. Third, the outcome might also be affected by the framing. We ask respondents whether they feel "well informed". In Experiment 2, we ask instead "how well informed" they feel. In this case, we find larger and significant effects on subjective knowledge about carbon pricing and the rebate (see Supplementary Tables 7 and 12). In the first experiment, only 8.1% (sd: 27.3%) [6.6% (sd: 24.8%)] of the sample strongly agree with being well informed (i.e., chose 6 or 7 on the 7-point Likert scale) about the carbon price [the rebate, respectively]. In the second experiment, the share of respondents stating to feel very well informed is between three and four times larger for both policy instruments.

We also elicit respondents' opinion on whether carbon pricing and the rebate have positive effects on protecting the climate. In the case of the rebate, we find no significant treatment effects. According to economic theory, lump-sum rebates only affect emissions by increasing disposable income which, in turn, also increases consumption of carbon-intensive goods. This effect is shown to be negligible[27]. While we find that the control group is also neutral about the climate effect of carbon pricing (with a mean of 3.5 on the seven-point answer scale), both the administrative cost (T1.3) and steering effect (T1.4) treatments significantly increase agreement with the statement that carbon pricing protects the climate. In the latter case (T1.4), this outcome is consistent with our expectations as the treatment explicitly explains how carbon pricing reduces emissions. However, the emission abatement induced by it is not contingent on the administrative cost of a rebate. Hence, we would not anticipate T1.3 to have any effect in this case. Carbon pricing is often regarded as a means of raising public revenue, despite its primary economic function as an incentive to mitigate emissions[14,28]. As the treatment text also states that below-average emitters are rebated more money than they incur costs, respondents might believe that the objective of carbon pricing is to fund payments rewarding climate-friendly consumers. If this were the case, whether revenues are wasted on administrative costs should actually affect the effectiveness assessment of a rational, informed individual.

We draw two main conclusions from providing general information in Experiment 1. First, it shows that many citizens are unaware of effective instruments to reduce carbon emissions. The data further show that market-based instruments of climate policy are highly complex and people might need even more information than our treatments provide in order to feel

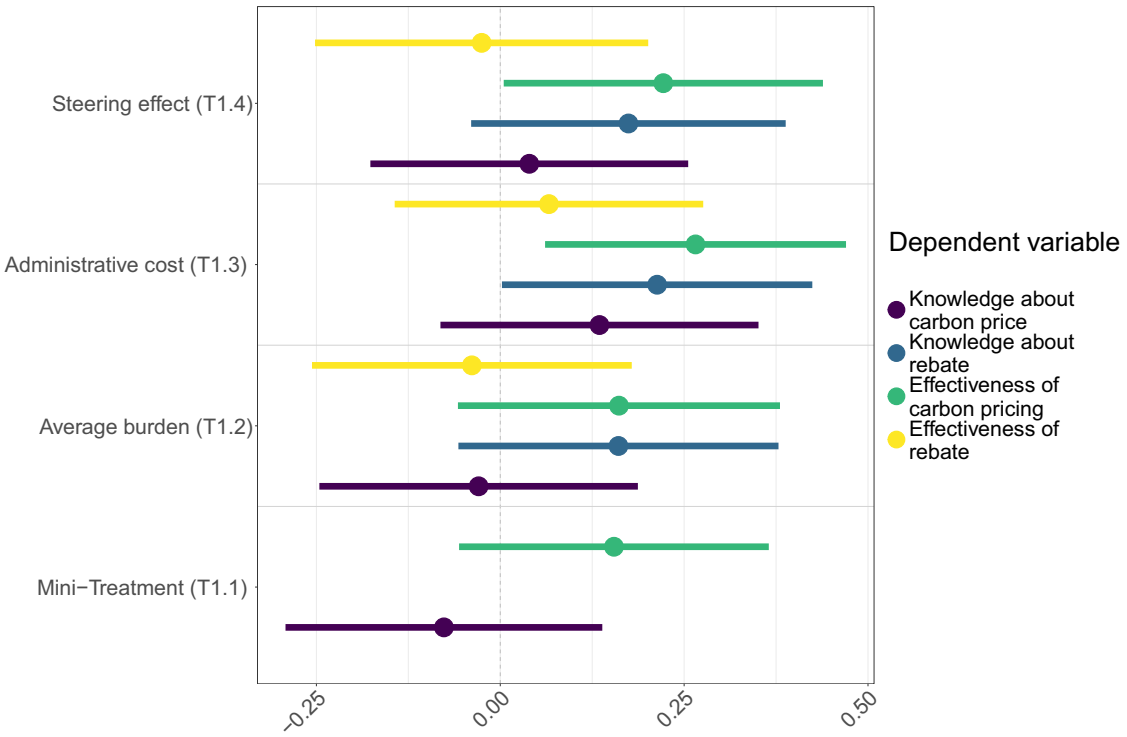


Fig. 2 | Subjective post-treatment knowledge and environmental effectiveness in Experiment 1. Notes: Regression of knowledge and perception of per-capita rebates and carbon pricing on the information treatments in the Experiment 1. Horizontal bars represent the 95%-CIs. For full regression results (with controls), see Supplementary Table 4 and Supplementary Table 9. All dependent variables are z-scored. Since the control group is not questioned about the rebate, we use T1.1 as the reference group for questions about the rebate. Errors are heteroscedasticity robust standard errors. The dependent variables refer to the following items in the questionnaire: *Knowledge about carbon price*: I feel well informed about the carbon price. *Knowledge about rebate*: I feel well informed about the climate money. *Effectiveness of carbon pricing*: The carbon price has a positive effect on climate protection. *Effectiveness of rebate*: The climate money has a positive effect on climate protection.

confident about their knowledge. Second, providing more (or more accessible) information could additionally bolster the positive effect on the support for carbon pricing.

Heterogeneous impact of personalized feedback

At the end of Experiment 1, respondents were asked to estimate whether they were below-average carbon emitters who would receive a refund exceeding their respective carbon price burden, average emitters whose costs would be roughly offset by the refund or above-average emitters whose costs exceed the rebate. Only 7% of the sample expected to be above-average emitters, while 57% considered themselves to be average, and 36% believed to be below-average emitters. This reveals a stark bias in respondents' self-assessment. To address this bias, Experiment 2 first asks respondents to answer a number of questions regarding their diet, consumption and mobility patterns which enables us to rank respondents' carbon footprints relative to the average individual[29] and provide personalized feedback (these questions are asked before respondents self-assess their carbon footprint and the expected net monetary impact of the policy package, details are available in the "Methods" section). Since below-average emitters are overcompensated by a per-capita rebate, a substantial share of the respondents should also anticipate earning a net gain from the rebate before receiving personalized feedback.

All the general information provided by the individual treatments in Experiment 1 is bundled into a single "full information" treatment (T2.1). As the novelty of experiment 2, we provide personalized feedback in a second treatment (T2.2), informing respondents not only about their relative carbon footprints but also whether they are "winners" who may expect a monetary gain, i.e., overcompensation, or "losers" who will experience a carbon price burden exceeding the rebate. The labels "winner" and "loser" are not used in the questionnaire but only for ease of reference in the paper. In the first step, we run an OLS regression, as reported in Fig. 3, to examine the effects of both treatments on support. Consistent with Experiment 1, we find that neither the full-information treatment nor personalized feedback increase support for the rebate. However, the full-information treatment is only effective at fostering support for carbon pricing in general at the 10% level with a lower point estimate than its proximate counterparts (T1.3 and T1.4) in Experiment 1. Additionally, we find no significant effect on higher carbon prices. As a combination of the two most effective treatments from Experiment 1, we would expect to observe positive and even larger effects on support than in Fig. 1. This apparent inconsistency can be explained to a large degree by deliberate modifications of the questionnaire, but may also be driven by the exogenous impact of the energy price crisis. First, we employ a slightly better informed control group in the second experiment (similar to the mini-treatment in Experiment 1). As the information treatments only have a small impact on policy preferences, minor changes in the coefficients can already have strong implications for statistical significance. If we also employ the mini-treatment as the reference category in Experiment 1, the difference between the surveys already appears less stark (see Supplementary Table 11). Second, to leave less room for interpretation, we clarified the wording of the question regarding support for the carbon price mechanism from whether the carbon price "should be maintained" (in the German translation of the questionnaire, there is a small chance that it is interpreted as "freezing the price at its current level") to whether respondents consider it a "sensible political measure". Third, all treatments (including the control group) in Experiment 2, explicitly state that the carbon price was subject to a temporary freeze in 2022 due to the energy price crisis. We deem this necessary to account for the exceptionally broad coverage of energy prices in the media at the time of conducting Experiment 2. At the same time, this new information may trigger an increased aversion against even higher fossil fuel prices caused by carbon pricing.

In contrast to the muted impact of the general information treatment, personalized feedback significantly increases support for carbon pricing in

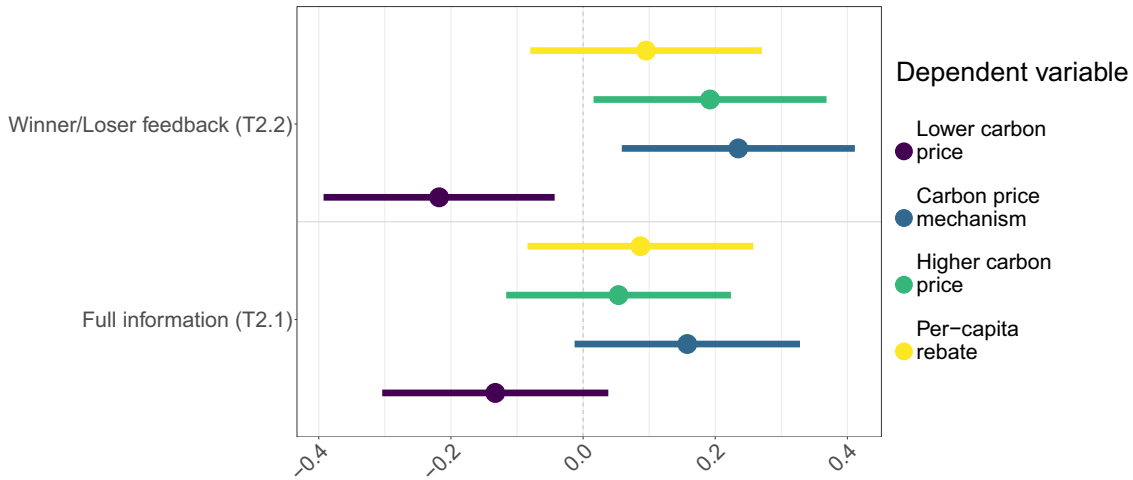


Fig. 3 | Support for carbon pricing and revenue rebating in Experiment 2. Notes: Regression of support for per-capita rebates and carbon pricing on the information treatments in Experiment 2. Horizontal bars represent the 95%-CIs. For full regression results (with controls), see Supplementary Table 5 and Supplementary Table 10. All dependent variables are z-scored. Errors are heteroscedasticity robust standard errors. The dependent variables refer to the following items in the questionnaire: *Per-capita rebate*: The climate money should be introduced. *Carbon price mechanism*: The carbon price is a sensible political measure. *Higher carbon price*: The carbon price should be increased. *Lower carbon price*: The carbon price should be decreased.

general and even for higher prices. We also find that respondents become significantly less supportive of reducing carbon prices. As in the first experiment, we find significant treatment effects for women when we exclude men from the baseline specification. Interacting the control variable for gender with the treatment variables reveals that women's support for carbon pricing is significantly affected by receiving personalized feedback. However, in contrast to Experiment 1, we cannot confirm heterogeneous treatment effects along gender as the interaction terms remain largely insignificant. Controlling for other socioeconomic variables neither affects the size nor significance of the treatment effects. Since respondents with below-average carbon footprints are overrepresented in the personalized feedback despite random assignment, we include the carbon footprint index as an additional control in Experiment 2.

The model in Fig. 3 does not account for the possibility that the effect of personalized feedback could vary depending on whether respondents learn to be winners or losers. We expect would-be winners to become more favorable towards carbon pricing and even support higher price levels as their net gains increase with the carbon price (as long as it still is on the increasing side of the Laffer curve). For given environmental preferences, a rational, self-interested loser should be less inclined to support carbon pricing in general and even ask for lower price levels. As the personalized feedback is a non-randomized treatment, we cannot directly compare the feedback groups to each other. Instead, we use respondents from the full-information treatment (T2.1) who would have received the same feedback as a reference point.

The top half of Fig. 4 reports the effect of receiving the "winner" feedback by comparing respondents with below-average carbon footprints to whom we disclose personalized feedback (T2.2) to the subset of below-average emitters who do not receive any information pertaining to their type (T2.1). Isolating the effect on respondents who learn to be over-compensated, we find a comparably strong and significant effect on support for the per-capita rebate, consistent with how we would predict a rational agent to act based on neoclassical utility maximization. Notably, in a separate regression for the "loser" feedback, we find no (negative) effect on support for the rebate of disclosing that the respondent is likely to be under-compensated (see bottom half of Fig. 4), although even would-be losers are better off with a rebate in place than in the case of an uncompensated carbon price. Taken together with the findings reported above, learning about the compensating nature of rebates appears to be only relevant when it is clear that people earn a direct monetary net gain. This is in line with previous studies which do not find effects for information on the redistributive property[21] or effectiveness and fairness but for individual costs[22]. Our results appear to corroborate that, in order to foster support for the rebate scheme, information should address the self-interest channel.

Additionally, disaggregating the effect of the personalized feedback reveals that the positive effect on carbon pricing in general and higher prices in particular is driven by respondents receiving the winner feedback. Further, would-be winners increase their rejection of lowering the carbon price to a similar magnitude. The point estimates for the coefficients are even larger than in the pooled treatment despite comparing to the full-information treatment instead of the control group (compare Figs. 1 and 3). In contrast, we find no significant effect of the loser feedback on any measure of support. Surprisingly, would-be losers are not even more inclined to ask for a lower carbon price as would be predicted by utility maximization. This finding has strong implications for policy design: it is not necessary to only reveal personalized feedback about the relative carbon footprint and expected net burden to winners, which might not only be administratively infeasible but also ethically questionable. Instead, higher overall support for carbon pricing can be achieved by disclosing personalized feedback to the entire population.

Personalized feedback and information updating

To identify to what extent personalized feedback is internalized and able to induce a change of prior beliefs, all respondents in Experiment 2 were also asked to assess their carbon footprints relative to the average consumer pre-treatment. Those who received personalized feedback (T2.2) were asked again post-treatment to evaluate whether belief updating takes place, i.e., if administering personalized feedback has an effect on self-assessment. Respondents underestimate their carbon footprint in comparison to the average consumer. Figure 5a shows that nearly all respondents in T2.2 believe they are below-average or average carbon emitters while, according to the carbon footprint index, 44% are actually above-average emitters. Only 5% of the respondents who were identified as above-average emitters, would correctly self-assess pre-treatment (compare Supplementary Table 13). The share of respondents who correctly identify as above-average emitters increases by 15pp after the treatment, primarily driven by people who revise their prior assessment of being below-average. Nonetheless, 80% of above-average emitters still believe to have a lower relative carbon footprint than suggested by the feedback (see Supplementary Fig. 4).

Respondents are substantially less optimistic about the net monetary impact of carbon pricing in combination with a per-capita rebate. Figure 5b and Supplementary Table 14 show that, prior to the treatment, only 12% of

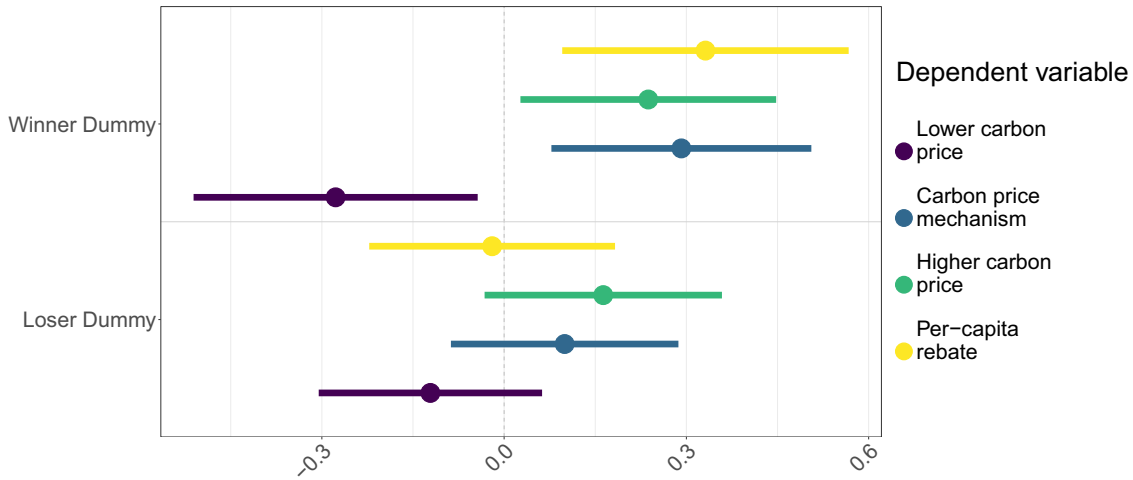
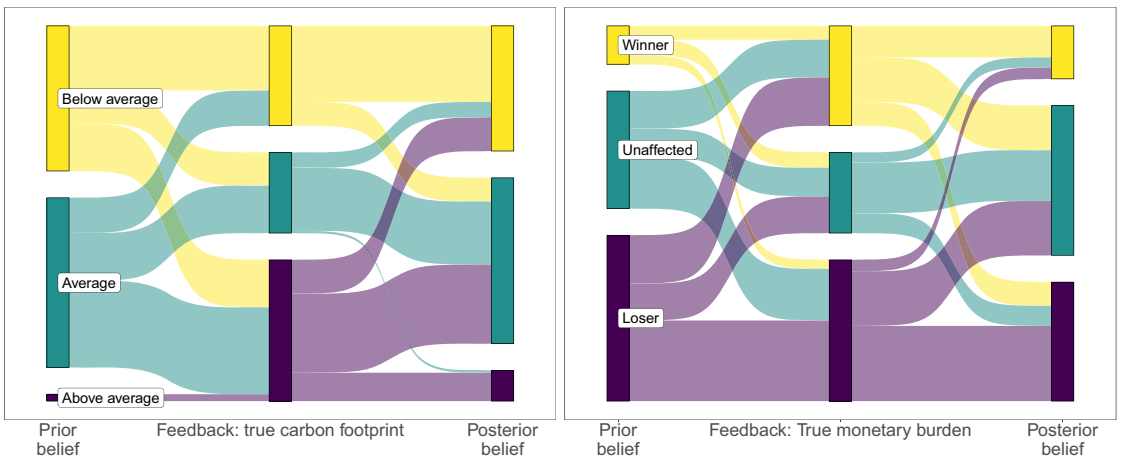


Fig. 4 | Change in support depending on feedback type in Experiment 2. Notes: Regression of support for per-capita rebates and carbon pricing on personalized feedback in Experiment 2. Horizontal bars represent the 95%-CIs. Only below-average carbon consumers, i.e., winners (top half of the table) [above-average carbon consumers, i.e., losers (bottom half)] in treatment groups T2.1 and T2.2 are considered. The Winner [Loser] dummy indicates whether a respondent received personalized feedback. The reference group consists of respondents assigned to T2.1 who would have received a winner [loser] feedback if they had been assigned to T2.2. The full set of control variables is included (see Supplementary Table 6 for the set of controls) and standardized. All dependent variables are z-scored. Errors are heteroscedasticity robust standard errors. The dependent variables refer to the following items in the questionnaire: *per-capita rebate*: The climate money should be introduced. *carbon price mechanism*: The carbon price is a sensible political measure. *higher carbon price*: The carbon price should be increased. *lower carbon price*: The carbon price should be decreased.



(a) Self-assessed relative carbon footprint (b) Self-assessed net impact of carbon price and rebate

Fig. 5 | Belief updating process induced by personalized feedback. a Self-assessed relative carbon footprint. **b** Self-assessed net impact of carbon price and rebate Notes: Stacked bars depict the shares of respondents treated with personalized feedback who self-assess their relative carbon footprint [net monetary impact of the policy] as belonging to each respective category (Below-average/Winner, Average/Unaffected, Above-Average/Loser) pre-treatment, i.e., prior beliefs (first stack of bars in the respective figures), the true share of each type in the sample (second stack of bars) post-treatment, i.e., posterior beliefs (third stack of bars). As true type and personalized feedback coincide, the horizontal flow connections between the left [right] and middle bars indicate the respective proportions of respondents with correct beliefs before [after] the treatment. The crossing flow connections indicate the proportion with wrong beliefs before (after) the treatment. In **a**, prior beliefs are elicited by asking: "*What do you think - How large is your carbon consumption compared to an average person in Germany?*" Posterior beliefs are measured by the question: "*You already estimated your carbon consumption before. What is your final assessment of your carbon consumption?*" In **b**, pre- and post-treatment beliefs both are elicited by the question: "*Do you think that the climate money will cover your carbon costs?*".

the respondents receiving personalized feedback believe to be winners, while the actual share amounts to 31%. Revealing the feedback induces partial belief updating. On the one hand, the respective shares of respondents who correctly self-identify as winners or being unaffected roughly double. On the other hand, the share of would-be winners who believe to be unaffected also increases by 7pp. Apparently, some respondents, who expected to be losers pre-treatment, are willing to update their beliefs but are cautious to completely embrace the winner feedback. Additionally, the feedback mechanism is ineffective when informing about being a loser. The share of respondents who correctly self-identify as losers even declines by 4pp after receiving the personalized treatment.

These results imply that respondents are subject to an environmental *Lake Wobegon effect*[30], i.e., they assess their lifestyles to have considerably smaller environmental impacts than suggested by the data. A priori, 98% of all respondents believe they have a below-average or average carbon footprint which is consistent with findings in the literature indicating that people typically underestimate their relative climate impact[31]. At the same time, they over-proportionally expect to be would-be losers of the policy package.

This may be directly linked to the gross overestimation of the financial burden associated with carbon pricing. When asked to estimate the monthly burden for an average household, respondents overshoot the actual value of EUR 120 fivefold on average (see Supplementary Fig. 2). Apparently, respondents fail to identify the direct link between carbon footprint and net carbon price burden when asked about their prior beliefs. This relation is made explicit by the information treatment such that, in case of perfect updating, posterior beliefs should be fully accurate or at least correspond to the self-assessed carbon footprint. There is mixed evidence in the experimental literature as to whether people employ Bayesian updating or asymmetric updating in favor of good news[32]. In either case, we would expect more respondents to embrace the winner feedback. However, consistent with French data, where respondents were even more reluctant to accept the winner feedback[5], a considerable gap remains between self-assessing as a would-be winner and having a below-average carbon footprint. In both our and the French sample, biased posterior beliefs are correlated with a lack of trust in the feedback (p-value = 0.006 for the Chi-squared test). Thus, public information campaigns must not merely focus on providing objective information but also consider how credibility can ensure maximum impact of the intervention.

Learning rates

The above findings indicate that revealing the loser type does not act as an "information shock" on its recipients. However, it remains unclear if the support-enhancing effect of the winner feedback stems from self-assessed winners endorsing confirmation of their prior beliefs or an information shock on would-be winners, who held prior beliefs of being losers and subsequently update their beliefs. To evaluate the relevance of the belief-updating channel, we estimate the change in respondent's self-assessment of being a winner, loser or unaffected by rebating revenues from carbon pricing via[33]

$$\Delta\text{cost type}_i = \beta_0 + \beta_1\,\text{prior}_i + \beta_2\,\text{shock}_i + \beta_3\,X_i + \epsilon_i, \tag{2}$$

where the dependent variable

$$\Delta\text{cost type}_i = \text{prior}_i - \text{posterior}_i, \tag{3}$$

measures the difference between the prior and posterior beliefs about the net monetary impact of the policy package, i.e., respondents' self-assessment of being a would-be winner, loser or unaffected. The information shock associated with personalized feedback is defined analogously as

$$\text{shock}_i = \text{prior}_i - \text{feedback}_i. \tag{4}$$

In both cases, we assign the numerical values {winner, unaffected, loser} = {1, 2, 3}. If a respondent does not change their self-assessment during the experiment, the variable in (3) is equal to zero (regardless of what type they believe to be). For someone with the prior belief "loser" and receiving the "winner" feedback the variable shock_i is equal to 2. If a respondent holds an incorrect prior belief and subsequently updates in accordance with the feedback, $\Delta\text{costtype}_i = \text{shock}_i > [<]0$ for winner [loser] feedback.

The results from estimating equation (2) are reported in the first column in Table 1. The updating effect on respondents who expected to be winners pre-treatment is bounded above, i.e., they cannot update their beliefs to be "more" than winners after receiving the feedback. Similarly, the effect on respondents with the prior belief to be a loser is bounded below. The respective coefficients of the priors mechanically account for these corner solutions to prevent overestimating the effect of the shock variable. If respondents engage in perfect updating, the coefficient of the shock would approach 1. We find a significant and positive effect of 0.3, indicating that updating takes place, yet limited by sticky beliefs. While not updating is rational if the prior was already correct, 12% of the treated sample react erratically, revising their self-assessment in the opposite direction of the feedback or changing beliefs even though the feedback confirms their prior. Another 7% only update their beliefs by one increment, i.e., to being unaffected, upon receiving either a winner or loser feedback. Another 32% keep to their prior beliefs although it is inconsistent with the feedback. The linear specification of the shock variable is expedient to identify the degree of imperfect updating. However, the strength and direction of the feedback may have non-linear effects on the propensity to update. The second column in Table 1 employs a factor variable for each possible integer value on the interval [−2,2] that the shock variable can take. "Neutral" feedback, confirming initial beliefs ($\text{shock}_i = 0$) is employed as the reference category. Strong negative feedback (prior "winner" and feedback "loser") has no statistically significant effect on posterior self-assessment. This result should primarily be attributed to the fact that only a diminishing share of the sample has the prior belief of being a winner, even fewer of whom receive the loser feedback. Weak negative feedback is received by all respondents who initially believe to be winners but would be unaffected or those with a prior of being unaffected but actually losing. The same statistical limitation as for strong negative feedback applies here to a lesser extent, and we find a small effect significant at the 5% level. Positive feedback, both weak and strong, is received by the majority of our sample with highly significant effects on updating. While weak positive feedback would ideally induce $\Delta\text{costtype}_i = 1$, strong positive feedback should have double the effect. Both coefficients are well below 1, with the point-estimate for strong positive feedback only being 3/4 larger than for weak positive feedback. This suggests that respondents are more willing to adopt feedback that does not veer too far from their prior beliefs.

Table 1 | Information updating regarding self-assessed monetary net impact of policy package (Δcosttype)

	Linear shock variable	Factorial shock variable
Prior: winner	−0.263*	−0.353*
	(0.132)	(0.143)
Prior: loser	0.300**	0.322**
	(0.103)	(0.108)
Shock	0.304***	
	(0.079)	
Strong negative feedback		−0.115
		(0.246)
Weak negative feedback		−0.223*
		(0.113)
Weak positive feedback		0.394***
		(0.108)
Strong positive feedback		0.683***
		(0.177)
Num.Obs.	402	402
Reference category		Neutral feedback (feedback = prior)
R^2adj.	0.341	0.347

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Regression of change in self-assessed net monetary impact (Δcosttype) on the gap between prior self-assessment and personalized feedback (shock) in column 1 and on the strength and direction of the feedback in column 2. The dependent variable equals 0 if respondents stick with their initial beliefs. A positive sign indicates a more optimistic posterior belief. The dummy variables *prior: winner* and *prior: loser* control for heterogeneous initial beliefs compared to the reference group of respondents believing to be unaffected pre-treatment. Error terms are heteroscedasticity robust standard errors. The full set of control variables is included as in Supplementary Table 10 (without interactions) and standardized. Both prior and posterior beliefs are measured by the question. "*Do you think that the climate money will cover your carbon costs?*".

Discussion

We conduct two survey experiments in Germany to elicit the effect of general information and personalized feedback on the support for carbon pricing and per-capita rebates of the associated revenues. The first experiment shows that providing information intended to foster economic literacy about the average monetary burden of carbon pricing, its steering effect on emission-intensive consumption and the administrative cost of the rebate scheme increase the support for carbon pricing. The second experiment provides respondents with personalized feedback about their relative carbon footprints and whether they may expect a net monetary loss or gain after equal-per-capita revenue rebating. We find that personalized feedback significantly boosts support for carbon pricing. This effect is driven by the reaction of respondents learning to be below-average emitters who earn net gains from the policy package. To a larger, yet still limited, extent than in a comparable study in France[5], respondents prove willing to update their prior beliefs about their carbon footprints and the monetary impact of climate policy in a positive direction when provided with information challenging their initial self-assessment.

Our results indicate that people generally lack information about economic policy instruments such as carbon pricing as well as a suitable reference point to evaluate their carbon footprint. With carbon pricing extending in both scope and ambition across the globe, our experiments with German respondents offer insights for climate policy and climate communication. In the EU alone, numerous countries are scheduled to adopt a (potentially high) carbon price on heating and road fuels starting 2028. German respondents do not understand that and how carbon pricing can directly mitigate emissions, although a national pricing scheme has been in effect since 2021, with experience of carbon pricing in the electricity sector even dating back to 2005. The positive acceptance effect of explaining the mechanism is small, yet easily scalable to communication channels in practice. At the same time, high carbon prices without some form of (partial) compensation appear infeasible. To the best of our knowledge, the only direct, per-capita transfer comparable to the one discussed in the German context is Austria's "climate bonus". Every Austrian resident receives an annual bank transfer (or voucher if no bank details are available) which is tiered depending on the accessibility of public transport at the place of residence and reduced by half for children. Since this mechanism has been established only recently, research is still required to determine whether the climate bonus fares any better in terms of visibility and fostering public support than indirect systems which have already been in place, e.g., in Canada or Switzerland. Since these indirect channels are hidden away in income tax rebates or reduced health insurance contributions, it has been shown that they have no positive impact on the support for climate policy[24]. Thus, our finding that informing respondents, whether they will be over- or under-compensated increases overall support, may be particularly relevant for countries with existing, indirect compensation schemes.

Since the experiments are not incentivized, the question of external validity arises. The decisions made by the respondents are cost-free and people may act differently if they incur the actual costs of their decisions. We argue that the potential bias is limited in our study. In the first experiment, respondents do not learn whether they will win from the policy. In the second experiment, they only receive categorical feedback (winner, unaffected, loser), yet not how large potential gains or losses could be for the individual. Thus, we leave respondents with uncertainty about their costs and benefits which may induce exaggerated expectations about the net burden. The only incentivized study we are aware of in this context implies that conventional survey experiments such as ours even underestimate public support for carbon pricing[34].

Due to non-probabilistic quota sampling, Experiments 1 and 2 are comparable with regard to the socioeconomic characteristics of age, gender and federal state. However, treatment texts and questionnaires are not identical across both experiments, owing to the aim of testing two distinct research questions and the energy price crisis which is explicitly addressed in the treatment texts of Experiment 2. In the months intervening the two experiments, the energy price crisis reached its climax in Germany, with fossil fuel prices at record levels, an announcement to temporarily freeze the national carbon price and other sweeping relief measures[35]. As a result, the financial ramifications of higher energy prices became much more salient for the average individual. The effectiveness of information treatments is sensitive to framing and context which may, at least partially, explain why we find smaller effects of the general information treatment in Experiment 2. Public information strategies should then be carefully crafted to suit the specific context of current political debates. Further research on the narratives regarding climate policy instruments may be necessary to tailor communication to people's current views. Furthermore, our ability to decide which treatment text proves most effective in statistical terms is limited by the sample size. It is likely that public information campaigns are constrained by people's capacities to engage with extensive information. This gives importance to the question which parts of information provision are most effective in correcting misconceptions about climate policy instruments.

While a comprehensive literature has already examined public support for carbon pricing and preferences regarding revenue use, we believe that the results of our study still warrant further research into the effectiveness of information treatments for carbon pricing. For instance, while we find no detrimental effect on support from providing personalized feedback to respondents with above-average carbon footprints, who are net losers of the policy package, targeted information provision could prove effective and necessary to achieve larger effects on support than attainable via generic information. This may be of particular importance in the face of increasing misinformation about carbon pricing and climate policy in general, disseminated by political actors. Additionally, our results indicate that the support-enhancing effect of information provision is not necessarily mirrored by better subjective knowledge about carbon pricing which also may warrant future research. Finally, our study cannot shed light on the retention of treatment effects and the provided information. The practical relevance of information provision depends on the longevity after the experiment[36] and whether it is transposed to real-world policy interactions. While the literature provides some evidence for persistence[33], the relatively smaller impact of even "freshly" provided general information in Experiment 2 reiterates the potential importance of targeted, personalized information. To the best of our knowledge, there is no evidence on the retention rate of personalized information to date.

Methods

All our main outcome variables (i.e., support for maintaining the carbon price, a higher or lower carbon price and per-capita redistribution) are measured on seven-point Likert-type scales. To measure the treatment effects, we estimate linear regression models for two reasons. First, we consider the seven-point scale a relatively close approximation of the underlying continuous latent variable as compared to binary or commonly employed three- and five-point scales. Second, if we estimate an ordered-logit or probit model, marginal effects have to be separately computed for each individual answer category on the seven-point scale. We transform the scales of the dependent variables to z-scores by subtracting from every observation the control group's mean and dividing by the control group's standard deviation[37]. Since the interpretation of the scale can vary with respect to the question, we argue that an OLS model with a z-scored dependent variable is more informative as it allows comparability across items. All coefficients are tested with a two-sided t-test against the H0 hypothesis that the coefficient is equal to 0.

In the main specification of the model, we compute the treatment effects without additional control variables as respondents are randomly sampled into the treatment groups. The randomization offsets the effect of observed or unobserved characteristics that are not directly linked to variations in the effectiveness of the treatments themselves. In the Supplementary Notes, we report alternative specifications of the models with a set of standard socio-economic controls including income. Missing observations (50 in Experiment 1 and 70 in Experiment 2, respectively) are imputed

using the following equation

$$log(\text{net household income}_i) = \text{age}_i + \text{age}_i^2 + \text{educationlevel}_i + \text{size of hometown}_i + \text{region}_i + \text{gender}_i + \text{partnership dummy}_i + \text{number of adults in household}_i + \text{number of children in household}_i + \text{single parent dummy}_i + \text{employment dummy}_i.$$

Additional binary control variables are defined to be 1 based to the following conditions: "Urban area" for communities with a size of more than 100,000 inhabitants; "male" for respondents who report to be male, other options are aggregated into the value 0; "No specific party preference" for respondents who either state that they would not vote or preferred not to disclose their choice.

Experiment 1

Experiment 1 was conducted online from August 9 to 18 2022, as part of wave 8 of the recurring Planetary Health Action Survey (PACE) survey on climate communication. One overarching goal of the survey is to understand factors that affect the acceptance of climate protection measures and people's readiness to act against climate change[38]. The 878 respondents were sampled via an online survey company as a non-probability quota sample representative of the German population aged 18 to 74 along the criteria age x gender and place of residence on the aggregation level of federal states[39]. 40 observations were dropped in the data cleaning process. One respondent reported an excessively large household size (30,655 persons), and 39 respondents showed non-attentive answer patterns (we define respondents as non-attentive if they answer all 13 questions in the main part of our survey consistently with the same number on the 7-point Likert scale). A total of 838 viable observations remain in the sample. The questionnaire was asked in German. A literal translation, is provided in Supplementary Note 3.1.

The first experiment tests whether providing general knowledge about carbon pricing and the rebate scheme can foster acceptance for climate policy. Respondents are randomly assigned to either a control group or one of four information treatments. We incrementally increase how much information is provided with each treatment. The control group (CG1) is informed that a national carbon price of EUR 30 per ton of CO_2 (the price at the time of the experiment) is levied in Germany. The "mini-treatment" (T1.1) additionally learns about the government's plan to introduce a per-capita rebate (referred to as "climate money" in Germany) to compensate for the carbon price burden. The "average burden" treatment (T1.2) additionally informs about the average annual burden caused by carbon pricing and that rebating exactly offsets the average consumer's burden such that below-average carbon emissions result in a net monetary gain. The two remaining groups receive the same information as T1.2 enriched by information about *either* the administrative cost of the rebate scheme (T1.3) *or* the steering effect of carbon pricing (T1.4). We chose this design to avoid over-straining participants' attention and to elicit whether information about carbon pricing or the rebate scheme is more effective.

Support for carbon pricing and the refund scheme is elicited via three separate items. Respondents are asked (1) if they agree that the government should maintain a carbon price, (2) if they think that the carbon price should be increased and (3) if they think that a rebate via the "climate money" should be introduced. Discerning between the support for maintaining the carbon price and a potential future increase is important as the existing literature shows that support can decrease rapidly with higher prices[5–8].

Experiment 2

Experiment 2 was conducted online between September 18 and November 12, 2022 with a total of 1191 respondents. It was ensured that respondents who participated in Experiment 1 were excluded from the sample for Experiment 2. We increased sampling compared to Experiment 1 to ensure sufficiently large subgroups within each treatment for statistical testing. We randomly assign 183 respondents to the control group (CG2), 508 to the "full information" treatment (T2.1) and 502 to the "personalized feedback" treatment (T2.2). After data cleaning, 180 respondents remain in CG2, 492 in T2.1 and 419 in T2.2, respectively. We remove a total of 102 respondents from the sample for a remainder of 1091 viable observations in the sample. Of the omitted respondents 26 were affected by a random technical error which resulted in an incomplete questionnaire being supplied to them; 19 respondents were dropped for either estimating an excessively large average annual carbon price burden of more than EUR 100,000 pre-treatment or EUR 10,000 post-treatment (the true value of EUR 120 is disclosed as part of the treatment); 1 respondent reported an excessively large household size (54 persons); 13 respondents showed non-attentive answer patterns (we define respondents as non-attentive if they answer all 18 questions in the main part of our survey consistently with the same number on the 7-point Likert scale); 47 respondents were subject to a coding error in the index variable used for computing the carbon-footprint indicator. The questionnaire was asked in German. A literal translation, is provided in Supplementary Note 3.2.

In the analysis, we refer to below-average emitters as "winners" (as they earn a net gain from the rebate) and above-average emitters as "losers". These terms are not mentioned to the respondents during the survey. We assign more respondents to T2.2 because the personalized feedback of either being a winner, loser or unaffected by carbon pricing-cum-rebate is equivalent to a set of three individual treatments. Since the personalized feedback is not assigned randomly but contingent on the respondents' characteristics we need a reference group of similar size that does not receive the feedback (T2.1). Oversampling T2.1 as well enables us to compare individuals with identical carbon footprints but who differ in terms of having received the personalized feedback.

The personalized feedback is based on a carbon footprint index computed from a set of 21 questions designed to elicit the carbon-intensity of a respondent's energy consumption, housing, mobility, diet and consumption patterns. These questions are asked before our module on the questionnaire and are weighted to generate a score on a continuous seven-point scale (we employ a modified version of the index in Geiger et al.[29]). The respondents are sorted into groups of below-average, average and above-average emitters depending on their carbon footprint index. The index was fitted on the data from a previous PACE wave answered by a different set of respondents. The upper (lower) third of the respective distribution was defined as cut-off points for above-average (below-average) emitters. The likelihood of reporting a false feedback is minimized by classifying the middle third of the distribution as "about average" emitters. Supplementary Table 2 reports the summary statistics.

The results from Experiment 1 informed the design of the second experiment which consists of a control group and two information treatments. As the mini-treatment (T1.1) neither provided any substantial information to the effect of building economic literacy nor induced a significant effect on support, we provide the introductory text from the mini-treatment to the control group in Experiment 2 (CG2). Since the two most detailed treatments in Experiment 1 (T1.3 and T1.4) both significantly bolster support for carbon pricing with no sign of information overload, we combine these into one treatment (T2.1) which now comprises all the general knowledge provided in our survey. With the energy price crisis at its climax while conducting Experiment 2 and high public attention to energy prices, all respondents (including the control group) are additionally informed that the national carbon price was introduced before the crisis and would not be increased in 2023 as a means to alleviate the price burden.

Furthermore, Experiment 1 showed that respondents substantially underestimate their carbon footprints, raising the question why support for carbon pricing with rebates remains at low levels when the majority of the sample (implicitly) expects to be either unaffected or even benefit. As the novelty of Experiment 2, respondents in the second treatment group (T2.2) receive personalized feedback about their carbon footprint and expected net monetary burden on top of the full set of general information provided in T2.1.

Our two main measures of support for climate policy remain unaltered, i.e., we ask (1) if respondents think that the carbon price should be increased and (2) if they think that a per-capita rebate should

be introduced. To account for the updated design, we add two new items. Namely, (3) if they think that the carbon price should be decreased, and (4) if they think that carbon pricing is a sensible means of climate policy in general. We expect item 3 to attain high support from above-average emitters if they act as self-interested utility maximizers. Item 4 is introduced to obtain a more abstract measure of support if the price level is not specified. This item indicates whether people oppose carbon pricing per se or are just afraid of stark price hikes.

Data availability

All data and code is available via: https://osf.io/fxreq/.

Code availability

Code is accessible via https://osf.io/fxreq/.

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Author contributions

M.K., K.R., M.J., L.L., H.T., and C.B. contributed to the design of the experiment; M.J., L.L., and H.T. contributed to the implementation of the experiment. M.G. and L.L. contributed to the design and implementation of the feedback treatment. M.K., K.R., and M.G. contributed to the data analysis. M.K., K.R., M.J., L.L. and C.B. contributed to writing the manuscript. All authors have read the manuscript and approved the final version.

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Competing interests

The authors declare no competing interests.

Additional information

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