Perceived fairness of personal carbon budgets: Evidence from a vignette experiment

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Short summary

Personal carbon budgets have been discussed as a measure to reduce CO_2 emissions, but can face resistance by the public, if perceived as unfair. One approach to increase fairness is social stratification, where carbon budgets are allocated based on individual circumstances. However, social stratification creates additional administrative costs, which are often overlooked by the public. This study investigates the perceived fairness of different designs of personal carbon budget schemes. Using a vignette experiment, respondents evaluate six scenarios that vary in allocation (equal vs. stratified) and amount of budget that can be traded, both before and after receiving information about the costs of stratification. By using a hierarchical Bayesian cumulative logit model, we find that on average scenarios with social stratification are perceived as fairer than equal allocation ones and that making respondents aware of the administrative cost of social stratification does not change the perceived fairness of carbon budgets.

Keywords: personal carbon budgets, transport justice, vignette experiment, fairness, Bayesian statistics

1 Introduction

To meet environmental targets, every sector of the economy is required to reduce its CO_2 emissions. In the transport sector efforts to reduce emissions increasingly demand policy approaches that go beyond efficiency improvements and target individual behaviour directly. One approach that has gained growing attention in both research and policy debates, including in Germany, are personal carbon budgets (PCB) (Stark & Marquart, 2024). This concept builds on the logic of emissions trading, extending it from firms to individuals. Under a PCB scheme, a budget of allowable emissions is allocated to each individual. Individuals are expected to manage their emissions within this limit, making trade-offs between carbon-intensive activities, like travelling.

Such measures, however, may encounter resistance, as they intervene in everyday practices. One way to increase policy acceptance is if citizens perceive climate measures not only as necessary but also as fair: Liebe & Dobers (2020) find that societal acceptance is crucial and closely tied to perceptions of distributive justice and fairness in the case of energy transition. In a meta-analysis from 33 countries, Bergquist et al. (2022) demonstrate that fairness and perceived effectiveness are the strongest determinants for climate change policies. While Maestre-Andrés et al. (2021) shows that for the acceptance of carbon taxes perceived fairness is even more important than perceived effectiveness of the policy.

In the case of PCBs, their design and implementation are still under development (Pitkänen et al., 2022; Fuso Nerini et al., 2021). However some studies have already investigated how PCBs could be designed to increase public support. For example, Bristow et al. (2010) show that tradability of carbon allowances can increase perceived fairness by introducing flexibility and individual choice. Evidence from Pitkänen et al. (2022) show that the allocation of emission rights is the decisive feature shaping perceived fairness. Their results indicate that policy designs that account for heterogeneous mobility needs are perceived as fairer than uniform allocations. In a qualitative study in Germany Stark & Marquart (2024) find a clear preference for social stratification of PCBs, where social stratification refers to the differentiation of carbon budget allocations based on individual circumstances, such as mobility needs, household composition, or spatial context. One problem related to accounting for heterogeneous needs in designing PCBs is the introduction of additional administrative costs, something which citizens may not be aware of.

This study investigates whether socially stratified personal carbon budget are perceived as fairer than if carbon budgets are the same for everyone. It also examines whether making the additional costs of social stratification explicit affects the perceived fairness of carbon budgets. To answer these questions we conduct a vignette experiment.
In our empirical analysis a hierarchical Bayesian cumulative logit model is used so as to estimate the effects of the different features of the PCB scheme and of individual characteristics on perceived fairness. By linking climate policy design with survey-derived evaluations of fairness, the study contributes to understanding the social feasibility of ambitious mitigation instruments.

2 Methods

Survey design

To investigate whether different designs of PCB are perceived differently we conducted a vignette experiment. Vignette experiments are a method where participants are presented with hypothetical scenarios with varying attributes and are asked to evaluate them. Respondents were asked to rate each vignette based on a 5-point Likert scale ranging from very unfair (1) to very fair (5). Each vignette has features: 1) the initial allocation of carbon budgets and 2) the level of trading allowed. The initial allocation is either a scenario in which all households receive the same amount of PCB for their mobility or one in which households with special circumstances receive larger PCBs. For simplicity, we refer to the two as equal allocation and stratified allocation of PCB for mobility, respectively. The trading dimension captures the degree to which households are allowed to trade their allocated budgets with other households. This gives households the possibility to exceed their allocated PCB by purchasing some from other households who sell their unused budget. Here, we presented respondent with three scenarios, namely 100%, 70% and 0% trading, where 0% implies that households that have exhausted their mobility budget need to switch to carbon-free transport mode or limit their mobility. In total there are $2 \times 3 = 6$ different vignettes. An example of a vignette reads as follows: "The CO_2 allowance is allocated in such a way that households with special circumstances [as explained in introduction] receive larger budget amounts. If households need additional CO_2 allowances, they have to by them, where households are able to sell up to 70% of their unused CO_2 allowances."
After having rated the six vignettes, respondents received information about the costs related to stratified allocation. It read: "The CO_2 budget for households can be calculated in a way that takes special circumstances into accountsuch as a remote location, a long commute, or a large family. But this also implies more bureaucracy and higher costs. If everyone receives the same CO_2 budget, less administrative effort and lower costs are required". After this treatment, respondents were asked to rate the six vignettes again.

Data

Data were collected through an online survey conducted in June 2024. Participants were recruited by a panel provider. After cleaning, the final sample consists of $N = 1,099$ participants who rated 12 vignettes respectively, for a total of 13,188 responses. The data also contain information about socio-demographics including gender, age, education level, net equivalent household income, disability, children in the household, and car ownership. Summary statistics for all variables used in the model are provided in Table 1.

Model

We estimate a hierarchical Bayesian cumulative logit model to capture the differences in perceived fairness of the six different PCB designs before and after receiving information about costs related to stratified allocation. The likelihood function of the observed rating y_{ivt} for individual $i \; \forall \; i \in 1, \ldots, N$, of vignette v (V=6) at time t, where $t = 0$ before and $t = 1$ after the information

Table 1: Summary statistics of variables used in the model (N = 1,099)

Variable	**Category**	**(%)**
Gender	female	49.0
	male	51.0
Age	[18-35]	16.9
	(35-55]	59.2
	55+	23.8
Education	high school	68.6
	bachelor+	31.4
Household equivalent net income	[0-1900]	18.2
	(1900-2350]	26.0
	(2350-2820]	13.2
	(2820-3500]	18.6
	3500+	24.0
Region	rural	28.1
	suburban	30.6
	urban	41.3
Kids in the household	yes	23.2
	no	76.8
Car ownership	yes	82.5
	no	17.5
Disability	yes	22.5
	no	77.5

treatment, is specified as follows:

$$y_{ivt} \sim G(\eta_{ivt}) \tag{1}$$

$$\Pr(y_{ivt} = k) = \Lambda(\tau_k - \eta_{ivt}) \; - \; \Lambda(\tau_{k-1} - \eta_{ivt}) \tag{2}$$

$$\Lambda(\eta_{ivt}) = \; \frac{1}{1 + e^{-\eta_{ivt}}} \tag{3}$$

$$\eta_{ivt} = \alpha_i + \alpha_{v[i} + \alpha_{g[i]} + treat_i\gamma + \gamma_{t[i],g[i]} + \gamma_{t[i],v[i]} + z_i\beta \tag{4}$$

where G is the cumulative distribution function of the inverse-logit link function, τ_k are threshold parameters; η_{ivt} is the set of linear predictors where α_i is a varying intercept for each individual (i=1,...,N fix everywhere), $\alpha_v[i]$ is a varying intercept for each vignette(v=1,..,V), $\alpha_{g[i]}$ is a varying intercept for group g and person i is member of group g where there are $g = 1, .., J$ and $J = 27$ groups based on every combination of socio-demographic characteristics in Table1, namely age, kids and net equivalent household income. The parameter γ measures the overall average effect of providing information about administrative costs in the case of socially stratified PCB allocation on perceived fairness; $\gamma_{t[i],g[i]}$ captures the differences in the effect of the information treatment by group g and $\beta_{t[i],v[i]}$ the effect of the information treatment by vignette; z_i is a vector of covariates including gender, education level, disability, and car ownership. . Prior distributions for parameter in the likelihood were specified as follows:

$$\alpha_i, \alpha_v, \alpha_g, \tau_k \sim \text{Student-t}(4; 0; 2, 5) \tag{5}$$

$$\beta_t, \beta_g, \beta_v, \gamma \sim \text{Student-t}(4; 0; 2, 5) \tag{6}$$

$$\sigma_i, \sigma_v, \sigma_g \sim \text{Student-t}^{+}(4; 0; 2, 5) \tag{7}$$

where σ_i is the standard deviations of the individual level intercepts, σ_v is the standard deviation of the vignette-level intercepts and σ_g is the standard deviations of the group level intercepts. The hierarchical priors allow to pool information across individuals, vignettes and socio-demographic

groups. They shrink parameters towards the mean according to the amount of information provided by the data, so that reliable parameters can be estimated also for groups with few observations. This process called regularisation and together with pooling provides robust estimates and allows to quantify uncertainties through the joint posterior distributions of the parameters. (Gelman, 2006). The joint posterior distribution, consisting of the likelihood function and the prior probability distributions, is estimated using Markov-Chain-Monte-Carlo (MCMC) methods using the R package brms version 2.23.0 (Bürkner, 2017) and the probabilistic programming language Stan (Stan Development Team, 2026). Every parameter is estimated with 4 independent MCMC chains and 4000 iterations. Different model specifications were estimated. The final model was selected using Pareto Smoothed Importance Sampling Leave One Out cross validation (Vehtari et al., 2017), which weights model complexity against generalisability by ensuring that the joint posterior distribution is not overly influenced by single observations.

3 Results and discussion

Table 2: Posterior means of parameter estimates, sd = standard deviation, l-95% CI = lower 95% credible interval, u-95% CI = upper 95% credible interval

	Estimate	**l-95% CI**	**u-95% CI**
Multilevel hyperparameters			
individual sd (σ_i)	2.69	2.55	2.83
soc-dem group sd (σ_g)	0.24	0.02	0.54
soc-dem group sd (σ_{tg})	0.19	0.07	0.32
vignette sd (σ_v)	0.41	0.19	0.92
vignette sd (σ_{tv})	0.22	0.08	0.55
Regression parameters			
intercept (τ_1)	-3.24	-3.99	-2.49
intercept (τ_2)	-1.15	-1.90	-0.41
intercept(τ_3)	1.07	0.33	1.82
intercept(τ_4)	4.08	3.33	4.82
information treatment (γ)	-0.01	-0.24	0.22
female (β_1)	0.31	-0.03	0.64
bachelor+ (β_2)	0.04	-0.30	0.38
disability (β_3)	-0.02	-0.42	0.39
car ownership (β_4)	-0.43	-0.94	0.04
region: urban (β_5)	0.31	-0.08	0.71
region: suburban (β_6)	0.13	-0.27	0.54

Table 2 reports the posterior means of the parameters. The standard deviations (sd) show that the individual differences in ratings is the largest source of variation (individual sd = 2.69), followed by vignette-level (0.41) and group-level variation (0.24). This finding is consistent with existing literature showing that individual attitudes toward climate policies are highly heterogeneous and only weakly explained by socio-demographic characteristics (Bergquist et al., 2022). It also shows that accounting for individual differences in how people respond to Likert-scale type questions is important to be able to uncover systematic differences of interest, even if small. The standard deviation of the interactions of the group effects with the treatment indicator and of the vignette effects with the treatment indicator are similar in size and small (0.19 and 0.22). This means that respondents react similarly to the additional information received regardless of their demographic group membership or of the vignette scenario. The posterior means of the vignette-specific varying intercepts are shown in Fig 1 and of the vignette-specific changes in rating after treatment are shown in Fig. 2.

In addition, most of the other socio-demographic variables included in the model have little association with perceived fairness as shown by the coefficients and the 95% credible intervals in Table 2.

Car ownership exhibits a negative association with fairness suggesting that individuals owning a car tend to perceive carbon budgets as less fair. This aligns with previous research showing that car dependence reduces policy acceptability (Maestre-Andrés et al., 2019).
Fig. 1 shows the posterior means of the varying intercepts for the six vignettes and their 95% credible intervals. It shows that vignettes with socially stratified PCB are perceived as fairer than vignettes where each person is allocated the same amount of carbon budget. This is in line with result from a survey of structured statement by Pitkänen et al. (2022). The also find in Finland that allocation schemes accounting for heterogeneous needs are perceived as fairer than equal allocations. The scenario that is perceived to be as fairest is the one where the allocation of PCBs is socially stratified and people cannot trade their unused allowances. The option of being allows to trade has no clear effect in the case of stratified allocation, while in the case of equally allocated PCBs no trading is considered as the most unfair. This suggests that trading is mainly valued as a way to compensate for unequal needs when the initial allocation does not reflect individual circumstances. If allocation already accounts for these differences through stratification, trading becomes less fair.

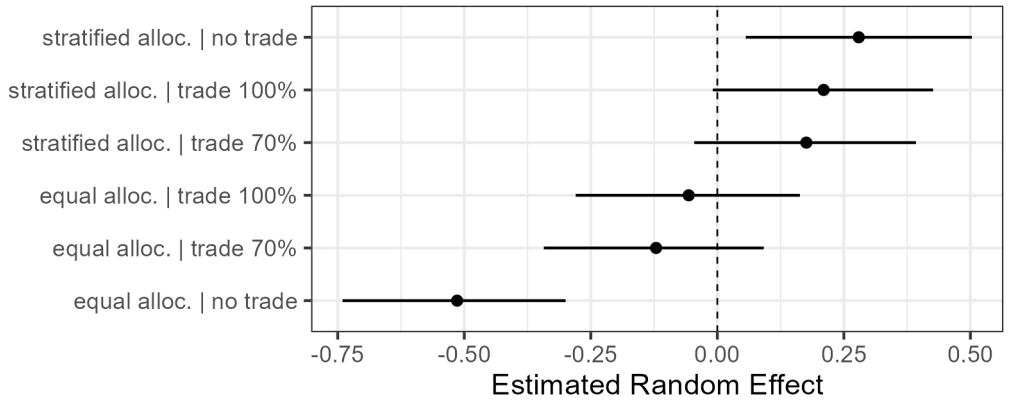


Figure 1: Estimated random effects pro vignette

Fig. 2 shows differences in perceived fairness by vignette and before and after receiving information about the costs of a socially stratifying the PCB allocation. On average, the treatment has no significant impact on perceived fairness of PCBs as also shown in 1. When looking at the change for each vignette, they are small. The only vignette where 95% credible interval of the posterior means does not overlap is the one with stratified allocation and no trade. This suggests that making administrative costs for stratified allocation clear to respondents slightly reduces the perceived fairness of this latter scenario. However, the change in average rating from to 2.96 to 3.07 is of no practical relevance. We therefore conclude that overall informing respondents about administrative costs does not change the perceived fairness of the different PCB schemes. Possible explanations are that respondents may have already been aware of higher administrative costs associated with socially stratified PCB allocations, when giving their first set of responses, or this fact may have been on no consequence to them and therefore their rating did not change. Another explanation is that the negative effect of higher costs could be offset by increased transparency, which has been shown to enhance perceived fairness (Maestre-Andrés et al., 2021).

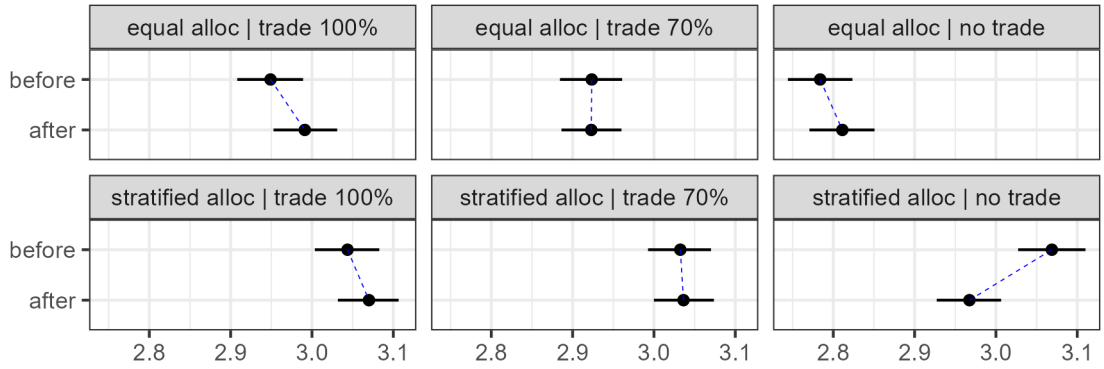


Figure 2: Posterior predictive mean of perceived fairness by vignette, before and after receiving information about administrative costs. The dotted blue line indicates the effect of the information treatment on perceived fairness of PCB for each vignette.

4 Conclusion

This study investigates how the design of different schemes of PCB influences their perceived fairness. It finds that socially stratifying the allocation of PCBs is seen as fairer compared to a situation where everybody receives the same amount. This holds even when the additional costs of social stratification are pointed to to respondents. Thus, citizens prefer PCB schemes that take the heterogeneous needs of different groups into account. Policymakers should consider this when designing a scheme for PCB and possibly when designing climate policies in general.
Our results show that the role of trading depends on how the carbon budget is allocated. Trading is perceived as fairer when budgets are distributed equally, as it allows individuals to adjust for differences in their needs. This suggests that trading can serve as a compensatory mechanism when allocation does not account for heterogeneous circumstances.
Not being allowed to trade is perceived as less fair than allowing 70% or 100% trading, but only when the same PCB amount is allocated to each individual. This shows that respondents prefer the opportunity of being able to increase their PCBs, if socially stratified PCB are not possible.
Finally, variation across individual needs to be modeled especially in case of Likert-scale outcomes in order to capture systematic differences, which otherwise may remain undiscovered, especially if they are small.

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