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Towards a representative social cost of carbon

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Abstract

The majority of estimates of the social cost of carbon use preference parameters calibrated to data for North America and Europe. We here use representative data for attitudes to time and risk across the world. The social cost of carbon is substantially higher in the global north than in the south. The difference is more pronounced if we count people rather than countries.
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[1] We are grateful to Moritz Drupp for sharing unpublished data from the expert survey.

Preprint

1. Introduction

The social cost of carbon is the damage done, at the margin, by the emission of carbon dioxide. Many assumptions are used to estimate the social cost of carbon. Most of these assumptions are positive; the climate sensitivity is a prime example. Some assumptions are normative; the pure rate of time preference comes to mind. Reasonable people can reasonably disagree about the social welfare function (indeed, Arrow, 1950, shows they cannot agree). An individual's ethical views are partly idiosyncratic and partly cultural. Norms about time and risk have been found to systematically vary between countries. The social cost of carbon, however, is primarily estimated by researchers from North America and Western Europe. In this paper, we recalibrate the social cost of carbon according to the stated preferences of people from 76 countries across the world.

Figure 1 groups 323 papers on the social cost of carbon by the country of affiliation of the authors of these papers (data from Tol, 2024a). Papers of mixed nationality are attributed proportionally to the number of authors. The USA contributed most (46%) followed by the UK (20%). Africa and Latin America did not contribute to this literature. Only three non-Western countries are represented, all from East Asia. There is no reason to believe that people from different parts of the world would systematically differ in their interpretation of the evidence about climate change and its impact, but they may well hold different attitudes to the future. The literature on the social cost of carbon may thus be biased towards Western attitudes.

"Western attitudes" contain a multitude, of course. There has been a lively debate on the pure rate of time preference in the context of climate policy, first between Nordhaus (1992) and Cline (1992), and later between Stern et al. (2006) and Nordhaus (2007). Arrow et al. (1996) described this as a choice between descriptive and prescriptive discounting. The range of opinions expressed in Drupp et al. (2018) shows that the debate has not abated. In fact, the discussion has become more complicated as alternatives to exponential discounting and its measurement have emerged (Cropper et al., 1991, Weitzman, 2001, Newell and Pizer, 2003, Tol, 2013, Giglio et al., 2014, Iverson and Karp, 2021, Jaakkola and Millner, 2022, Bauer and Rudebusch, 2023, Eden, 2023).

Participants in this debate draw, almost exclusively, from Western cultures. The *prescriptive* school relies, essentially, on Aristotle's verdict against usury, which was later adopted by St Augustine and the Prophet Muhammad. The *descriptive* school typically calibrates time and risk preferences with data for the market for U.S. Treasuries. Sohn (2019) is an exception, estimating the social cost of carbon using time and risk preferences based on data from South Korea. In an attempt to reflect a wider range of opinions, Anthoff et al. (2009) reflect a wider range of opinions, using the 20 OECD countries in Evans (2005). Data for the rest of the world has since improved considerably and this allows us here to cast a wider net and so be more inclusive and representative of the world population.

The paper proceeds as follows. Section 2 presents the data and methods. Section 3 discusses the results. Section 4 concludes.

2. Materials and methods

2.1. Data and calibration

Falk et al. (2018) and Falk et al. (2023) report attitudes towards time and risk for 76 countries,[2] which together constitute 85% of the world population and 93% of the world economy. These preferences are stated in responses to intuitive questions in an unincentivized survey. Falk *et al.* show that these simple measures correlate well with the results of state-of-the-art preference elicitation in surveys and experiments. They further show that stated preferences do not systematically differ from revealed preferences in incentivized elicitation. Figure A.3 shows the indicators of patience and risk-taking, aggregated to the country level. The two measures are largely uncorrelated, with the possible exception for extreme impatience and risk aversion.

Note that, Falk *et al.* report indices for, rather than rates of, time preference and risk aversion. Sunde et al. (2022) calibrate rates to indices. We calibrate Falk's data to the results of Drupp et al. (2018), who surveyed 181 economists about the appropriate pure rate of time preference and the elasticity of intertemporal substitution, the two parameters in the Ramsey (1928) rule of discount. There are surveys of time preference (Frederick et al., 2002, Wang et al., 2016) and the elasticity of marginal utility (Havránek et al., 2015, Havránek, 2015, Thimme, 2017), but Drupp's is the only study we know that considers both together. We use a linear calibration, matching the 5% and 95%ile so that 90% of the imputed data are *interpolated* and only 10% *extrapolated*.

No calibration is perfect. The appendix details five alternative calibrations. One restricts the sample to Europe and North America, the location of most of Drupp's experts. A second alternative weighs Falk's country data by population size. The remaining three calibrations use alternatives to Drupp's data.

2.2. Model

We use FUND4.0M-G, one of a stable of integrated assessment models collectively known as FUND. This is a global model implemented in MATLAB. The model consists of a Solow (1956) growth model with energy (and associated emissions of carbon dioxide) as a derived demand rather than a factor of production, as in DICE (Nordhaus, 1993). Emissions are input into a Maier-Reimer and Hasselmann (1987) carbon cycle model which is coupled to a Schneider and Thompson (1981) climate model. Climate change feeds back on total factor productivity according to a damage function calibrated as in Barrage and Nordhaus (2023). The main departure from Nordhaus' seminal work is that we assume that society becomes less vulnerable to climate change as incomes grow (Schelling, 1984). This version of the model has been used previously (Tol, 2020, 2024b); earlier versions date back to Tol (1997).

The social cost of carbon is computed as the difference in relative impacts due to a small increase in carbon dioxide emissions in 2015, multiplied by total output in the unperturbed scenario, discounted with the Ramsey rate.

[2]The data are here.

3. Results

Figure 2 shows the cumulative frequency of the social cost of carbon for all 76 countries of the Falk data for the SSP2 scenario, which is the most likely scenario according to Srikrishnan et al. (2022). These estimates reflect what the global social planner would do if she assumed the average preferences of the people in one of the listed countries. The median country prefers a carbon tax of about \$10/tC, with opinions ranging from \$2/tC (5th %ile) to \$60/tC (95th %ile).

For comparison, Figure 2 includes the cumulative frequency for Drupp's 181 experts. The median scholar favours \$24/tC, much higher than the median country. Geographically limiting the calibration sample makes the global distribution look much like Drupp's sample. Population-weighting shifts the entire distribution to the left. The median person would prefer a carbon tax of \$4/tC.

The median scholar is in line, unsurprisingly, with the scholarly literature. Stern et al. (2006) advocate $\rho = 0.001$ and $\eta = 1$, which yields a social cost of carbon of \$48.8/tC. OMB (2023) sets the money discount rate at 2%, which NYSERDA and RFF (2021) argue implies $\rho = 0.003$ and $\eta = 1.3$. The social cost of carbon is then \$30.9/tC. Nordhaus (1992) prefers $\rho = 0.03$ and $\eta = 1$, resulting in \$15.4/tC while Nordhaus (2014) favours $\rho = 0.015$ and $\eta = 1.5$ and a social cost of carbon of \$15.8/tC. Weitzman (2007) is most in line with popular opinion, arguing for $\rho = 0.02$ and $\eta = 2$ and so \$8.8/tC.

Averaged over Drupp's experts, the social cost of carbon is \$34.8/tC. Averaged over the countries, the social cost of carbon is much lower, \$15.4/tC. It is higher, however, than the population-weighted average, \$12.2/tC. This is because more populous nations tend to be more impatient. If we use average preferences, the social cost of carbon falls further, to \$9.3/tC because the social cost of carbon increases disproportionally with decreasing time and risk preferences.

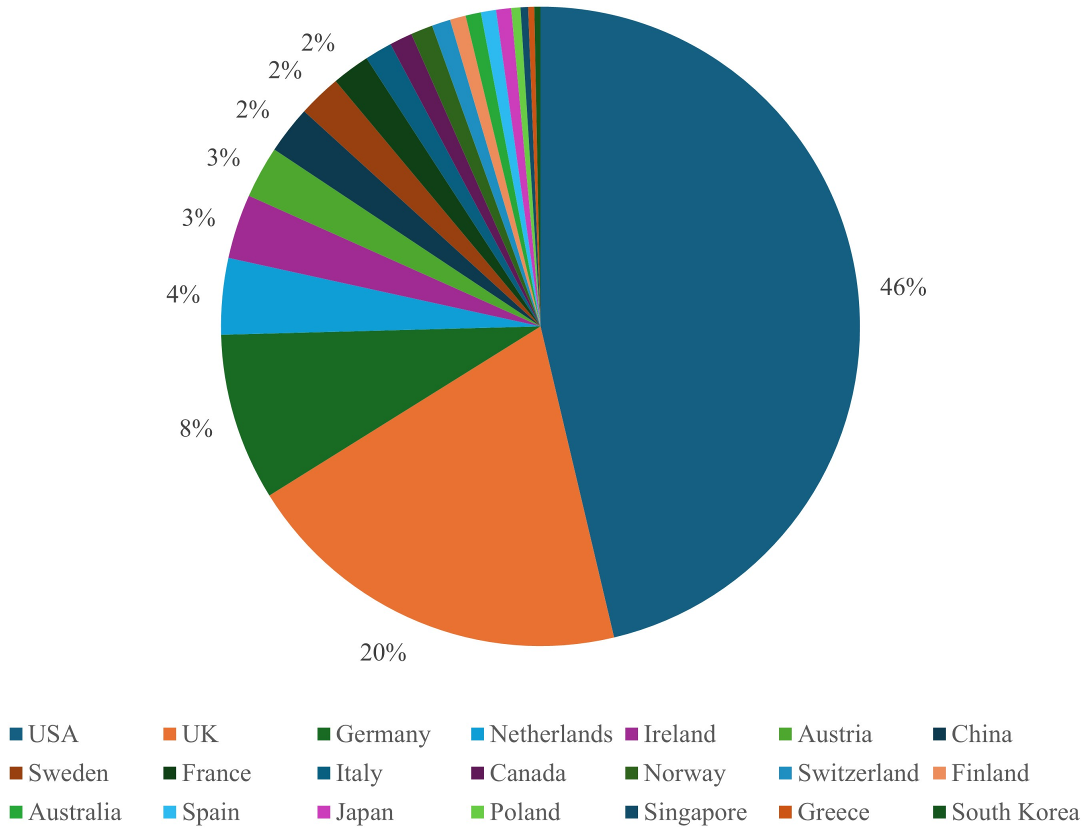
4. Discussion and conclusion

The literature on the social cost of carbon is dominated by Western scholars. We calibrate the pure rate of time preference and the rate of risk aversion to representative data for 76 countries. We find that Western scholars advocate a higher social cost of carbon than would national representatives. The social cost of carbon may fall further if we weigh the results by the number of people.

Having extensively surveyed the literature on the social cost of carbon (Tol, 2023, 2024a), we are fairly sure that this is the first paper to try and establish a *representative* social cost of carbon. It should not be the last. The Falk data are indicators of individual impatience and risk-taking that we *assumed* to be proportional to the presumably social pure rate of time preference and elasticity of intertemporal substitution according to Drupp. These studies are, in our opinion, the best available but not without flaws. Connecting two disparate datasets is never easy, but we here have a mismatch of both what is measured and where.

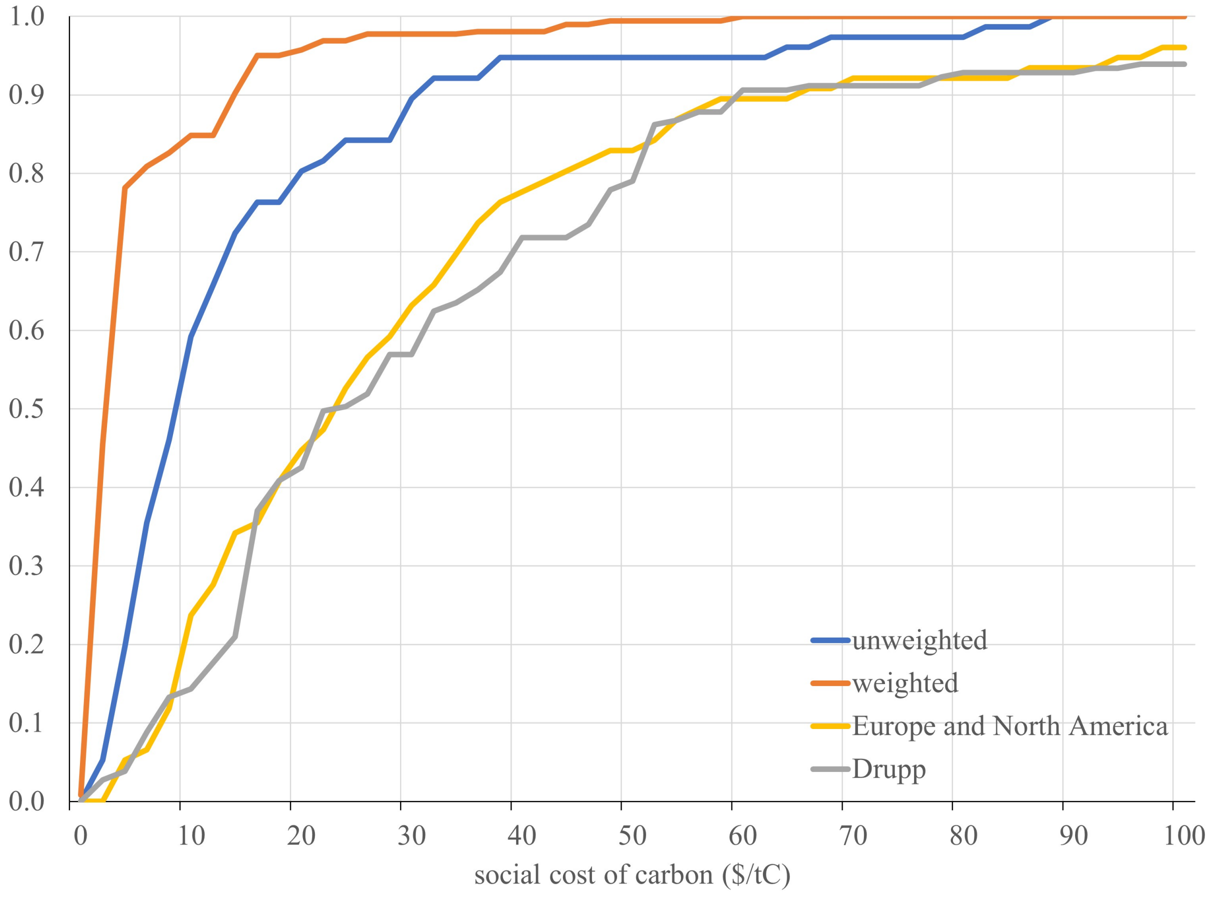
In the appendix, we also find somewhat different results for the Hofstede data and the literature review. The analysis here should therefore be repeated when better data become available. We abstract from uncertainty and inequity, and so dodge the question whether the inverse of the rate of intertemporal substitution equals the rate of risk aversion and the pure rate of inequity aversion (Agneman et al., 2024, Anthoff and Emmerling, 2019, Ha-Duong and Treich, 2004, Saelen et al., 2009, Tol, 2010). Neither the Drupp nor the Falk data allow us to make this distinction. We explored only a small part of the parameter and model space of the social cost of carbon: We use a model with a single region and a single sector; we abstract from the impact of climate change on economic growth; we ignore uncertainty, ambiguity, and stochasticity; we omit fat tails and tipping points; and so on. More research is therefore needed but—since none of these extensions affects the relationship between the social cost of carbon on the one hand and the pure rate of time preference and the elasticity of intertemporal substitution on the other—we are confident that this would not detract from our key finding: The ethical values assumed by experts systematically deviate from the world population so that published estimates of the social cost of carbon are unrepresentative and too high.

Figure 1: Share of papers published on the social cost of carbon by country of affiliation.



Papers published between 1980 and 2023. Papers are attributed to country of affiliation at the time of publication and inversely proportional to the number of co-authors. Source: Tol (2024a).

Figure 2: Cumulative frequency of the global social cost of carbon with national time and risk preferences.



Three cases are shown: The calibration of the Falk data to the Drupp data, the population-weighted calibration of the Falk data to the population-weighted Drupp data, and Drupp's expert data.

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Appendix A. Calibration

We impose the linear relationship $\rho_c = \gamma_\rho + \lambda_\rho r_c$ and $\eta_c = \gamma_\eta + \lambda_\eta e_c$ where ρ is the pure rate of time preference, η is the Arrow-Pratt rate of relative risk aversion, r is Falk's index of patience, e is Falk's index of risk-taking, γ_i and λ_i are calibration parameters, and c denotes country.

In the central calibration, we choose γ_i and λ_i such that the $\rho_{(c)} = r_{(c)}$ and $\eta_{(c)} = e_{(c)}$ for $(c) = 0.05$ and $(c) = 0.95$ of the Drupp and Falk data. We then use the calibrated parameters to derive the welfare parameters for each country. See Table A.2. Note that we impose the restrictions $\rho_c \geq 0$ and $\eta_c \geq 0$. We use the tails to calibrate so that 90% of the imputed data are *interpolated* and only 10% *extrapolated*.

Drupp's data are unrepresentative: 44% of the surveyed experts are in North America, 49% in Europe, and 7% in the rest of the world. The corresponding numbers for the world population in 2020 are 6%, 8% and 86%. This matters. In Falk's data, the patience (risk-taking) score is 0.80 (0.12) in North America, 0.28 (-0.09) in Europe and 0.00 (-0.07) in the rest of the world; these are population-weighted averages. We therefore weigh Drupp's data so that sample and population totals align. We similarly weigh Falk's data so that percentiles are for the world population. We then match the 5th and 95th percentiles of the weighted Drupp data with the weighted Falk data and continue as above. As an alternative solution to the lack of representation of Drupp's data, we restrict their data to experts from Europe and North America and similarly only consider Falk's data for these countries *in the calibration*.

As a robustness check, we use the 2015 version of the cultural dimension data by Hofstede (2003).[2] Particularly, we use long-term orientation as a proxy for pure time preference and uncertainty avoidance as a proxy for risk aversion and hence intertemporal substitution. Calibration is as for Falk. Hofstede has fewer countries (63) than Falk (76). More importantly, Hofstede focuses on *corporate* culture whereas Falk is about culture in general. Hofstede interviewed people who work for multinationals, whereas Falk interviewed residents. This is particularly problematic as relatively fewer people work in large corporations in poorer countries, and fewer still in foreign-owned ones.

As another robustness check, we survey the literature on the social discount rate for selected countries. We started with a search on SCOPUS for "social discount rate" and continued with checking the references of the papers found. The results are in Table A.1. We regressed the recommended pure rate of time preference on Falk's index of impatience, and the rate of risk aversion on Falk's index of risk-taking (with dummies for Iran and Russia). See Table A.2. We use two variants of this. In the first variant, we use the observed rates as given in Table A.1, or the average if there are multiple observations for a country; for those countries without any observations, we use the regression model. In the second variant, we use the regression model for all countries.

[2] The data are here.

The Drupp data are for the pure rate of time preference and the intertemporal rate of substitution. Although based on a survey, the respondents are experts who can be expected to understand both these concepts and the implications of their choice. The main disadvantage of the Drupp data is its lack of representativeness, not just because PhD economists are not like the general population but also geographically.

The literature on the appropriate social discount rate for various countries is more representative than Drupp's data but suffers other drawbacks. The pure rate of time preference is sometimes set by the authors based on convention. In other cases, it is based on the mortality rate. Although this approach has its supporters (e.g Addicott et al., 2020) and is reasonable for *private* decisions, it is not uncontroversial as a guide to *public* policy. The curvature of the utility function is measured in various ways—expenditure on necessary goods and redistribution through taxes and benefits being the most common ones—but not quite the elasticity of intertemporal substitution. However, together the alternative calibrations reveal key sensitivities and potential biases.

Table A.3 shows the details for each country. The first two calibrations see substantial variation between countries whereas all countries cluster near the average for the third calibration, particularly so for the variant in which all parameters are imputed. The Hofstede calibration uses a different set of countries and is therefore shown separately in Table B.10. Differences between countries are again substantial.

Figure A.1: Index of attitudes to time and risk according to Falk et al. (2018), by country.

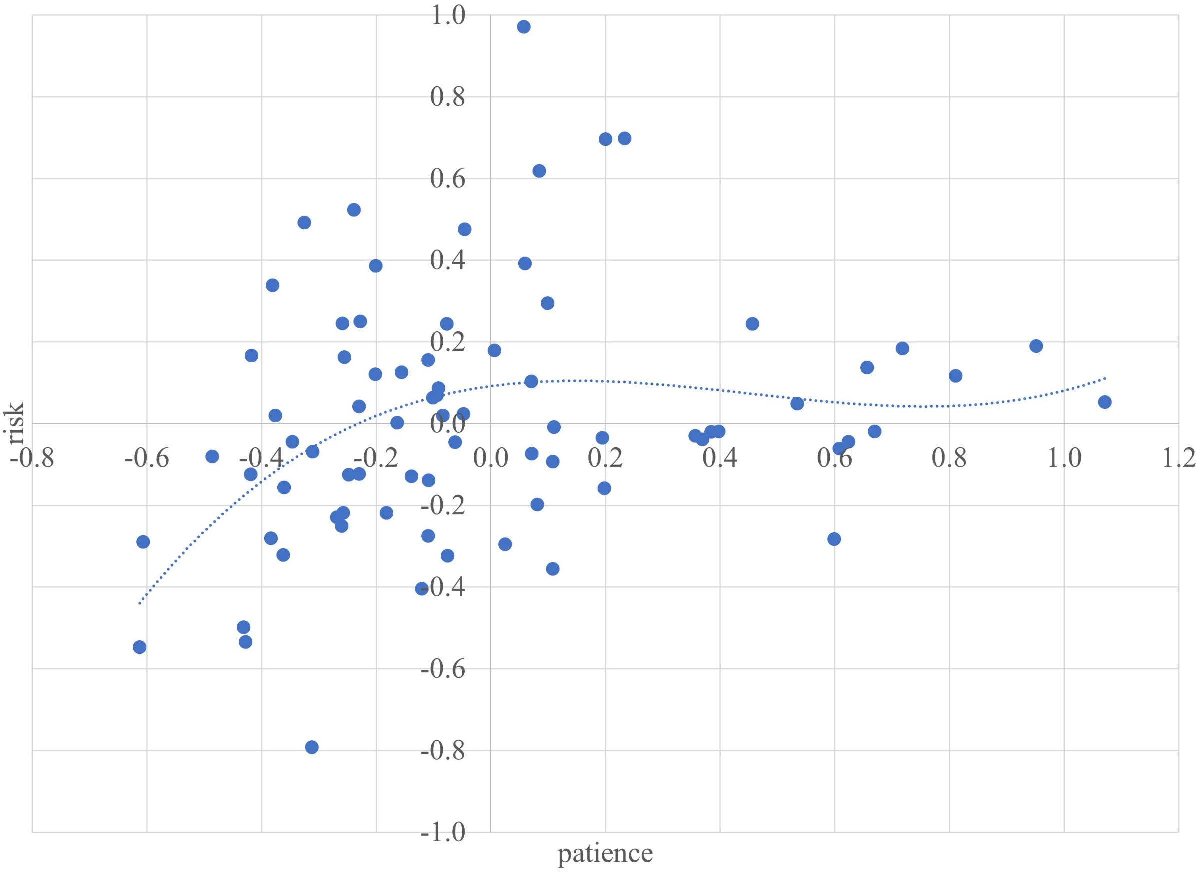


Table A.1: Published estimates of the social discount rate and its components for various countries

Study	Country	r	ρ	η
Moore et al. (2020)	Argentina	3.02	1	1.23
Villena and Osorio (2023)	Argentina	7.20	1.21	1.41
Evans and Sezer (2005)	Austria	5.3	1.0	1.6
Evans and Sezer (2004)	Australia	4.7	1.5	1.4 - 1.7
Evans and Sezer (2005)	Belgium	4.4 - 4.7	1.0	1.5 - 1.6
Moore et al. (2020)	Bolivia	2.81	1	1.06
Villena and Osorio (2023)	Bolivia	3.70	1.23	1.25
Moore et al. (2020)	Brazil	4.36	1	2.09
Villena and Osorio (2023)	Brazil	11.90	1.21	3.34
Boardman et al. (2010)	Canada	3.5	1	1.5
Moore et al. (2020)	Chile	5.72	1	1.22
Villena and Osorio (2023)	Chile	6.50	1.23	1.33
Wang et al. (2013)	China	4.5	0.672	1.07
Moore et al. (2020)	Colombia	4.61	1	1.61
Villena and Osorio (2023)	Colombia	5.00	1.30	2.02
Moore et al. (2020)	Costa Rica	3.16	1	1.11
Evans and Kula (2011)	Cyprus	4.1 - 5.0	1	1.0 - 1.3
Evans and Sezer (2005)	Czech Republic	3.1	1.1	1.4
Seçilmiş and Akbulut (2019)	Czech Republic	1.94 - 3.75	1.05	0.483 - 1.404
Evans and Sezer (2005)	Denmark	2.3 - 2.4	1.1	1.2 - 1.3
Moore et al. (2020)	Ecuador	2.48	1	1.06
Villena and Osorio (2023)	Ecuador	3.70	1.24	1.33
Moore et al. (2020)	El Salvador	3.43	1	1.13
Seçilmiş and Akbulut (2019)	Estonia	3.42 - 6.91	1.27	0.483 - 1.178
Evans and Sezer (2005)	Finland	4.5	1.0	1.6
Evans (2004), Evans and Sezer (2004, 2005)	France	3.2 - 3.8	0.9 - 1.2	1.3
Evans and Sezer (2004, 2005)	Germany	4.1 - 4.5	1.0	1.4 - 1.6
Schad and John (2012)	Germany	2.9	0.5	1.5
Evans and Sezer (2005)	Greece	4.8 - 5.3	1.0	1.5 - 1.7
Moore et al. (2020)	Guatemala	2.72	1	1.04
Moore et al. (2020)	Honduras	3.35	1	1.16
Evans and Sezer (2005)	Hungary	3.2 - 3.5	1.3	1.2 - 1.4
Tabi (2013)	Hungary	4.1	1.27	1.4
Seçilmiş and Akbulut (2019)	Hungary	2.11 - 3.30	1.32	0.483 - 1.000
Kula (2004)	India	5.2	1.3	1.64
Daneshmand et al. (2018)	Iran	5.79	0.53	4.266
Evans and Sezer (2005)	Ireland	5.6 - 6.8	0.8	1.6 - 2.0
Evans and Sezer (2005)	Italy	4.5 - 4.7	1.0	1.4 - 1.5
Percoco (2008)	Italy	3.69 - 3.83	1	1.282 - 1.347
Evans and Sezer (2004)	Japan	5.0	1.5	1.4
Seçilmiş and Akbulut (2019)	Latvia	3.50 - 6.67	1.42	0.483 - 1.092
Kazlauskiene and Stundziene (2016)	Lithuania	3.75	1.37	0.53
Evans and Sezer (2005)	Luxembourg	5.4	0.9	1.8
Moore et al. (2020)	Mexico	4.20	1	2.71
Evans and Sezer (2005)	Netherlands	3.6 - 3.8	0.9	1.5 - 1.6
Moore et al. (2020)	Nicaragua	3.36	1	1.14
Moore et al. (2020)	Panama	3.61	1	1.15
Moore et al. (2020)	Paraguay	1.99	1	1.00
Villena and Osorio (2023)	Paraguay	3.20	1.20	0.94
Moore et al. (2020)	Peru	3.93	1	1.05
Villena and Osorio (2023)	Peru	6.30	1.26	1.72
Evans and Sezer (2005)	Poland	6.1	1.0	1.1
Seçilmiş and Akbulut (2019)	Poland	2.75 - 4.94	0.98	0.483 - 1.085
Foltyn-Zarychta et al. (2021)	Poland	4.39	0.9599	1.1174
Evans and Sezer (2005)	Portugal	5.3 - 5.6	1.0	1.6 - 1.7
Kossova and Sheluntcova (2014, 2016)	Russia	3.2 - 3.9	1.48	0.2
Evans and Sezer (2005)	Slovakia	6.6 - 7.0	1.1	1.5 - 1.6
Seçilmiş and Akbulut (2019)	Slovakia	2.53 - 5.32	0.98	0.483 - 1.353
Sohn (2019)	South Korea	5.1	1.1	1.0
Evans and Sezer (2005)	Spain	4.7	1.0	1.6
Evans and Sezer (2005)	Sweden	2.4 - 2.8	1.1	1.1 - 1.4
Halicioglu and Karatas (2013)	Turkey	5.06	0.61	1.686
Akbulut and Seçilmiş (2019)	Turkey	4.41 - 4.88	0.58	1.0580 - 1.2042
Evans and Sezer (2002, 2004, 2005)	United Kingdom	4.2 - 4.8	1.0	1.5 - 1.6
Groom and Maddison (2019)	United Kingdom	4.5	1.5	1.5
Evans and Sezer (2004)	United States	4.4 - 4.6	1.5	1.3 - 1.4
Moore et al. (2013)	United States	3.5	1	1.35
Rennert et al. (2021)	United States	3.0	0.8	1.5
Moore et al. (2020)	Uruguay	4.64	1	1.71
Villena and Osorio (2023)	Uruguay	4.10	1.23	1.98
Moore et al. (2020)	Venezuela	2.81	1	1.04

The table shows the components of the Ramsey rule $r = \rho + \eta g$ where r denotes the discount rate, ρ the pure rate of time preference and η the inverse of the elasticity of intertemporal substitution.

Table A.2: Indicators and rates of time and risk preferences and the corresponding calibrations.

		r	e	ρ	η	constant	slope
Falk	5%ile	-0.43	-0.43	0	0.2	$\gamma_\rho = 2.46$	$\lambda_\rho = 3.60$
	95%ile	0.68	0.55	4	4	$\gamma_\eta = 1.77$	$\lambda_\eta = 2.87$
Population weights	5%ile	-0.38	-0.32	0	0.5	$\gamma_\rho = 3.28$	$\lambda_\rho = 4.57$
	95%ile	0.72	0.39	5	5	$\gamma_\eta = 2.95$	$\lambda_\eta = 6.34$
N America & Europe	5%ile	-0.35	-0.47	0	0.2	$\gamma_\rho = 2.79$	$\lambda_\rho = 3.00$
	95%ile	0.93	0.17	3.85	2.05	$\gamma_\eta = 0.70$	$\lambda_\eta = 2.88$
Table A.1						$\gamma_\rho = 1.07$	$\lambda_\rho = 0.03$
						$\gamma_\eta = 1.40$	$\lambda_\eta = 0.09$
Hofstede	5%ile	14.3	29.1	0	0.2	$\gamma_\rho = 4.78$	$\lambda_\rho = 0.055$
	95%ile	87.0	95.9	4	4	$\gamma_\eta = -1.02$	$\lambda_\eta = 0.042$

Falk reports patience and risk-taking whereas Drupp reports impatience and risk aversion. We therefore flipped Falk's sign.

Table A.3: National time and risk preferences for four alternative calibrations.

	Falk						Table A.1			
	unweighted		weighted		Eur & NAm		observed		imputed	
	ρ	η	ρ	η	ρ	η	ρ	η	ρ	η
Afghanistan	3.18	1.42	4.20	2.18	3.40	0.35	1.07	1.39	1.07	1.39
Algeria	2.24	0.65	3.01	0.46	2.61	0.00	1.06	1.37	1.06	1.37
Argentina	3.28	1.65	4.33	2.69	3.48	0.58	1.11	1.32	1.07	1.40
Australia	0.09	1.38	0.28	2.08	0.82	0.30	1.50	1.55	1.05	1.39
Austria	0.27	1.95	0.50	3.34	0.97	0.88	1.00	1.60	1.05	1.41
Bangladesh	2.16	2.34	2.91	4.21	2.55	1.27	1.06	1.42	1.06	1.42
Bolivia	2.20	1.47	2.96	2.29	2.58	0.40	1.12	1.16	1.06	1.39
Bosnia Herzegovina	3.35	2.13	4.41	3.75	3.53	1.06	1.07	1.41	1.07	1.41
Botswana	1.61	0.00	2.21	0.00	2.09	0.00	1.06	1.34	1.06	1.34
Brazil	3.39	2.49	4.47	4.54	3.57	1.42	1.11	2.72	1.07	1.42
Cambodia	2.89	2.93	3.83	5.52	3.15	1.87	1.07	1.44	1.07	1.44
Cameroon	4.00	3.31	5.24	6.34	4.07	2.24	1.08	1.45	1.08	1.45
Canada	0.00	1.24	0.00	1.78	0.64	0.17	1.00	1.50	1.05	1.38
Chile	3.02	1.41	3.99	2.15	3.26	0.34	1.12	1.28	1.07	1.39
China	1.02	1.83	1.46	3.07	1.60	0.76	0.67	1.07	1.06	1.40
Colombia	3.70	1.90	4.86	3.24	3.83	0.83	1.15	1.82	1.08	1.41
Costa Rica	3.04	1.77	4.03	2.94	3.28	0.70	1.00	1.11	1.07	1.40
Croatia	2.79	1.57	3.71	2.51	3.07	0.50	1.07	1.40	1.07	1.40
Czech Republic	1.07	1.83	1.53	3.08	1.64	0.76	1.08	1.10	1.06	1.40
Egypt	3.84	2.58	5.03	4.73	3.94	1.51	1.08	1.43	1.08	1.43
Estonia	2.37	2.62	3.17	4.82	2.72	1.55	1.27	0.83	1.07	1.43
Finland	0.30	2.58	0.54	4.74	0.99	1.52	1.00	1.60	1.05	1.43
France	1.17	1.86	1.65	3.14	1.72	0.79	1.05	1.30	1.06	1.40
Georgia	4.21	2.00	5.50	3.46	4.25	0.93	1.08	1.41	1.08	1.41
Germany	0.21	1.90	0.43	3.23	0.92	0.83	0.75	1.50	1.05	1.41
Ghana	2.15	0.00	2.90	0.00	2.54	0.00	1.06	1.35	1.06	1.35
Greece	3.75	2.22	4.93	3.95	3.87	1.15	1.00	1.60	1.08	1.42
Guatemala	3.38	2.40	4.46	4.34	3.56	1.33	1.00	1.04	1.07	1.42
Haiti	3.81	1.72	5.00	2.83	3.92	0.64	1.08	1.40	1.08	1.40
Hungary	4.01	3.20	5.25	6.11	4.08	2.14	1.30	1.10	1.08	1.45
India	2.85	2.56	3.78	4.69	3.12	1.49	1.30	1.64	1.07	1.43
Indonesia	3.76	2.69	4.94	4.99	3.88	1.63	1.08	1.43	1.08	1.43
Iran	3.83	0.80	5.02	0.81	3.93	0.00	0.53	4.27	1.08	1.37
Iraq	3.96	1.29	5.19	1.90	4.04	0.22	1.08	1.39	1.08	1.39
Israel	0.81	1.07	1.20	1.40	1.42	0.00	1.05	1.38	1.05	1.38
Italy	2.07	2.04	2.79	3.54	2.47	0.97	1.00	1.38	1.06	1.41
Japan	2.07	2.79	2.79	5.21	2.47	1.73	1.50	1.40	1.06	1.43
Jordan	3.96	2.13	5.20	3.74	4.05	1.06	1.08	1.41	1.08	1.41
Kazakhstan	3.39	1.07	4.47	1.39	3.57	0.00	1.07	1.38	1.07	1.38
Kenya	2.73	1.07	3.63	1.40	3.02	0.00	1.07	1.38	1.07	1.38
Lithuania	2.68	1.90	3.57	3.24	2.98	0.83	1.37	0.53	1.07	1.41
Malawi	2.62	0.41	3.49	0.00	2.93	0.00	1.07	1.36	1.07	1.36
Mexico	2.85	2.17	3.78	3.83	3.12	1.10	1.00	2.71	1.07	1.41
Moldova	1.75	1.87	2.39	3.17	2.21	0.80	1.06	1.41	1.06	1.41
Morocco	3.58	1.97	4.70	3.39	3.72	0.90	1.07	1.41	1.07	1.41
Netherlands	0.00	1.23	0.00	1.75	0.00	0.15	0.90	1.55	1.04	1.38
Nicaragua	4.66	3.34	6.08	6.42	4.63	2.28	1.00	1.14	1.08	1.45
Nigeria	3.18	0.66	4.20	0.50	3.39	0.00	1.07	1.37	1.07	1.37
Pakistan	2.76	1.71	3.66	2.82	3.04	0.64	1.07	1.40	1.07	1.40
Peru	2.85	1.33	3.78	1.97	3.12	0.25	1.13	1.39	1.07	1.39
Philippines	2.10	0.92	2.83	1.08	2.49	0.00	1.06	1.37	1.06	1.37
Poland	2.20	1.98	2.96	3.42	2.58	0.91	0.98	0.95	1.06	1.41
Portugal	3.58	4.05	4.71	7.98	3.73	2.99	1.00	1.65	1.07	1.47
Romania	3.42	2.43	4.51	4.40	3.60	1.36	1.07	1.42	1.07	1.42
Russia	2.73	2.70	3.63	5.00	3.02	1.63	1.48	0.20	1.07	1.43
Rwanda	4.64	2.60	6.05	4.79	4.61	1.54	1.08	1.43	1.08	1.43
Saudi Arabia	1.74	0.00	2.37	0.00	2.19	0.00	1.06	1.34	1.06	1.34
Serbia	2.95	2.14	3.91	3.77	3.21	1.07	1.07	1.41	1.07	1.41
South Africa	2.25	0.00	3.02	0.00	2.62	0.00	1.06	1.31	1.06	1.31
South Korea	1.13	1.88	1.60	3.20	1.68	0.81	1.10	1.00	1.06	1.41
Spain	1.74	2.23	2.38	3.95	2.20	1.16	1.00	1.60	1.06	1.42
Sri Lanka	2.82	1.59	3.74	2.55	3.09	0.52	1.07	1.40	1.07	1.40
Suriname	2.43	1.26	3.25	1.82	2.77	0.19	1.07	1.39	1.07	1.39
Sweden	0.00	1.62	0.00	2.62	0.00	0.55	1.10	1.25	1.04	1.40
Switzerland	0.04	1.83	0.22	3.07	0.78	0.76	1.05	1.40	1.05	1.40
Tanzania	3.63	0.36	4.77	0.00	3.77	0.00	1.08	1.36	1.08	1.36
Thailand	3.28	2.13	4.33	3.73	3.48	1.06	1.07	1.41	1.07	1.41
Turkey	2.63	1.70	3.50	2.80	2.93	0.63	0.60	1.32	1.07	1.40
Uganda	3.38	1.30	4.45	1.92	3.56	0.23	1.07	1.39	1.07	1.39
Ukraine	3.11	2.40	4.11	4.34	3.34	1.33	1.07	1.42	1.07	1.42
United Arab Emirates	2.79	1.52	3.70	2.40	3.07	0.45	1.07	1.39	1.07	1.39
United Kingdom	0.53	1.63	0.84	2.64	1.19	0.56	1.25	1.53	1.05	1.40
United States	0.00	1.44	0.00	2.21	0.36	0.36	0.90	1.43	1.04	1.39
Venezuela	3.28	1.05	4.32	1.37	3.47	0.00	1.00	1.71	1.07	1.38
Vietnam	2.06	1.80	2.78	3.00	2.46	0.73	1.06	1.40	1.06	1.40
Zimbabwe	3.32	0.27	4.37	0.00	3.51	0.00	1.07	1.35	1.07	1.35
average	2.51	1.75	3.34	2.97	2.81	0.79	1.07	1.42	1.07	1.40
weighted	2.24	1.95	2.99	3.37	2.58	0.94	1.03	1.46	1.06	1.41

Table B.4: Alternative estimates of the social cost of carbon.

Calibration	Falk			Table A.1		Hofstede
	unweighted	weighted	NAM & Eur	observed	imputed	
Average SCC	15.4	8.8	31.6	21.8	20.4	19.2
Weighted average SCC	12.2	27.9	5.9	22.6	20.3	51.4
SCC for average preferences	9.3	3.5	20.3	20.0	20.4	10.0
SCC for weighted preferences	8.6	3.1	18.9	19.5	20.3	22.5

The social cost of carbon is for emissions in 2015, given in $\$^{2015}$ per tonne of carbon. The top two rows are the (weighted) averages of the global social costs of carbon for national time and risk preferences; see Table B.6. The bottom two rows are for (weighted) average time and risk preference. Averaging is done with and without population weighting. The results are for three alternative calibrations of national time and risk preferences.

Appendix B. Additional results

Table B.6 shows the estimates of the global social cost of carbon for the SSP2 scenario, according to the preferences of each of the 76 countries. Four alternative calibrations of the national preferences are used; see Table A.3.

Table B.4 shows the aggregate results. The top row takes the average of the social cost of carbon—one country, one vote. The second row takes the population-weighted average—one person, one vote. The third row takes the average time and risk preferences instead, and the bottom row the population-weighted averages. The six columns show the six alternative calibrations. The first column calibrates to the Falk data, the second one to the population-weighted Falk data, the third one restricts the calibration to data from Europe and North America. The fourth column uses the observed preferences of Table A.1 where available and imputed preferences elsewhere. The fifth column imputes all preferences. The sixth column uses the Hofstede data.

In all six calibrations, the average social cost of carbon is larger than the social cost of carbon with average preferences. In other words, the social cost of carbon is a *convex* function of time and risk preferences, at least in the domain considered here. See Figures B.2 and B.3.

The results for the Hofstede calibration are in Table B.10. Figure B.4 plots the social cost of carbon against the unweighted Falk results for those countries that are in both datasets. The difference is clear. Hofstede's long-term orientation correlates with Falk's patience and uncertainty avoidance negatively correlates with risk-taking but those correlations are far from perfect: 0.29 and -0.33, respectively. However, as Figure B.4 shows, the correlation between the social cost of carbon when preferences are calibrated to Hofstede are negatively correlated (-0.28) to the Falk social cost of carbon. The bottom rows of Table B.10 corroborate the key qualitative result above: The social cost of carbon is very different when calibrated to the preferences observed in the rest of the world than when following people from Europe and North America.

The social cost of carbon is larger if we calibrate the Falk data to the risk and time preferences from the literature in Table A.1, primarily because the pure rate of time preference is much lower in this case, and particularly so in China.

The social cost of carbon, averaged over Drupp's experts, is higher than for all calibrations to the Falk data and the literature, and to three of the four Hofstede results. The exception is the population-weighted social cost of carbon for the Hofstede calibration. This is because people from China and India who work for foreign-owned companies are extraordinarily patient and risk-tolerant.

Table B.7 shows the social cost of carbon for alternative scenarios. The social cost of carbon is lowest for the SSP1 (SSP5) scenario for the Falk (literature) calibrations and highest for the SSP3 one. Our default scenario, SSP2, is in the middle of the range, regardless of calibration. The range in estimates is limited because scenarios deviate most from one another in the long run and these differences are discounted away. Table B.8 shows the sensitivity of the social cost of carbon to the impact function assumed. The base calibration is due to Barrage and Nordhaus (2023). If instead we fit the same function to the meta-analysis in Tol (2024a), the social cost of carbon falls. Relying on the earlier meta-analysis of Howard and Sterner (2017) raises the social cost of carbon. In the base case, vulnerability to climate change falls with economic growth, assuming an income elasticity of $\varepsilon = -0.36$. More (less) elastic vulnerability lowers (raises) the social cost of carbon. If we set the income elasticity to zero, the social cost of carbon goes up further. If vulnerability *increases* with development, as assumed by Sterner and Persson (2008), Drupp and Hänsel (2021) and van den Bremer and van der Ploeg (2021), the social cost of carbon is higher still \$30.9/tC.

Table B.5 uses k-means clustering on risk and time to group the 76 countries into 4 clusters. Cluster 3 combines a high time preference with a low risk aversion, cluster 4 is the opposite. Cluster 3 is the poorest, cluster 4 the richest.[3] Cluster 2 has high values for both, cluster 1 lower values. Incomes are about the same, in between clusters 3 and 4.[4] Cluster 2, which includes India, advocates the lowest social cost of carbon, in line with the high rates of time preference and risk aversion. Cluster 1 is the second-lowest. Cluster 3, the poorest cluster, favours the highest social cost of carbon: Their low rate of risk aversion dominates their high time preference. Cluster 4 is in between. For all four clusters, population weighting reduces the average social cost of carbon.

Clustering has little effect for the calibrations to the literature summarized in Table A.1 because there is so little variation between countries.

[3] Income was not used to cluster. Note that China clusters with the rich countries.

[4] Three-way clustering would allocate the countries in cluster 3 to clusters 1 and 2. Five-way clustering would split cluster 1. Four-way clustering leads to identical results with and without population-weighting of preferences.

Table B.5: Welfare parameters and the implied social cost of carbon for four clusters of countries.

cluster	1	2	3	4
Falk & Drupp				
Social cost of carbon ($/tC)	9.76	4.55	45.98	21.72
pure time preference	2.73	3.63	2.48	0.44
risk aversion	1.69	2.54	0.33	1.68
Falk & Drupp, population-weighted				
Social cost of carbon ($/tC)	4.00	1.63	25.97	6.72
pure time preference	3.56	4.14	3.58	1.12
risk aversion	3.04	4.67	0.42	2.89
Falk & Drupp, Europe & North America				
Social cost of carbon ($/tC)	21.52	9.36	47.00	48.62
pure time preference	2.97	3.36	2.99	1.32
risk aversion	0.76	1.48	0.00	0.67
observed and imputed				
Social cost of carbon ($/tC)	21.87	21.96	21.51	21.83
pure time preference	1.06	1.11	1.07	1.03
risk aversion	1.46	1.43	1.35	1.38
imputed				
Social cost of carbon ($/tC)	20.43	19.81	21.51	20.57
pure time preference	1.07	1.08	1.07	1.05
risk aversion	1.40	1.43	1.35	1.40
income (US$/person/year)	16,502	17,034	3,553	42,583
income (Geary-Khamis $/person/year)	9,438	6,257	1,529	34,997
population (millions)	1,449	2,495	590	2,147

The 2015 social cost of carbon ($\$^{2015}$/tC) is the average of the global social costs of carbon for national time and risk preferences in the respective clusters. Averages are unweighted unless indicated otherwise. Clusters are found by k-means clustering on time and risk preferences.

Figure B.2: The social cost of carbon plotted against the calibrated pure rate of time preference.

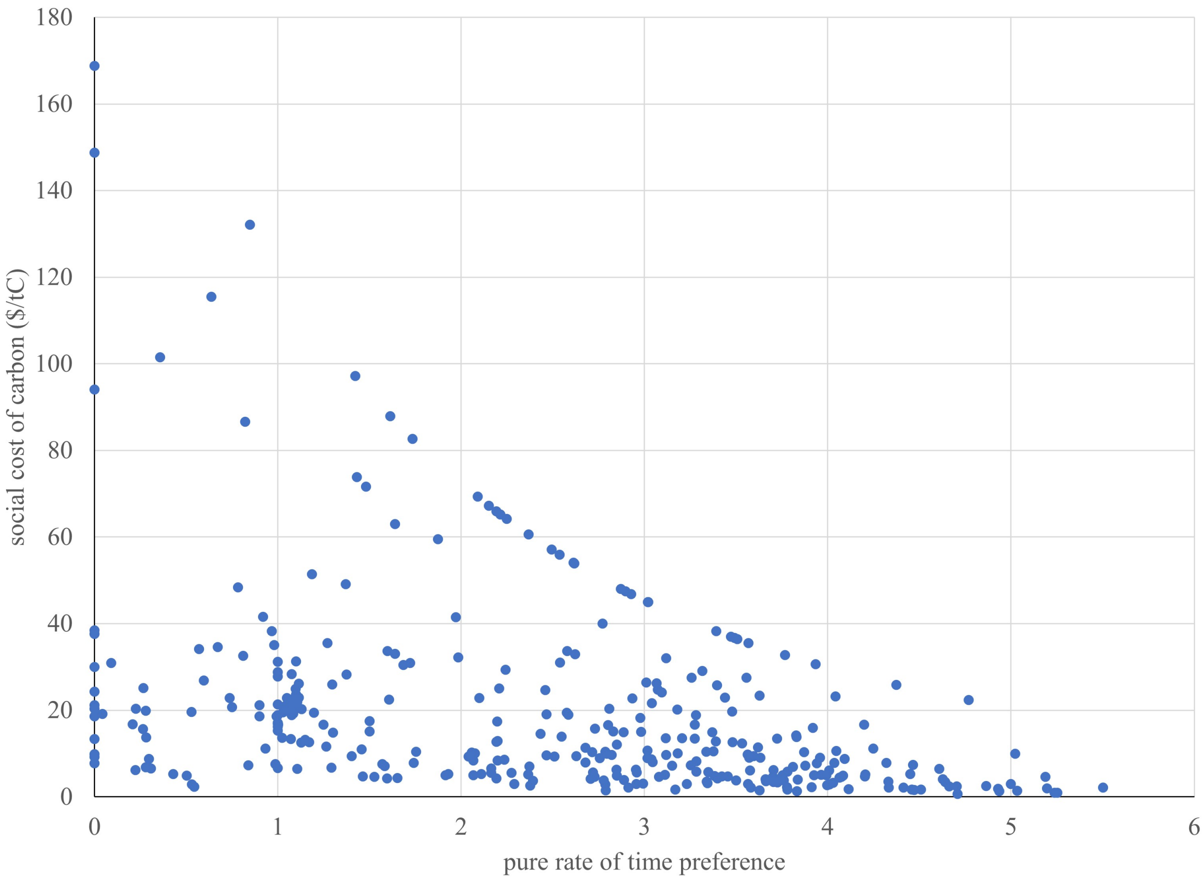


Figure B.3: The social cost of carbon plotted against the calibrated inverse of the intertemporal rate of substitution.

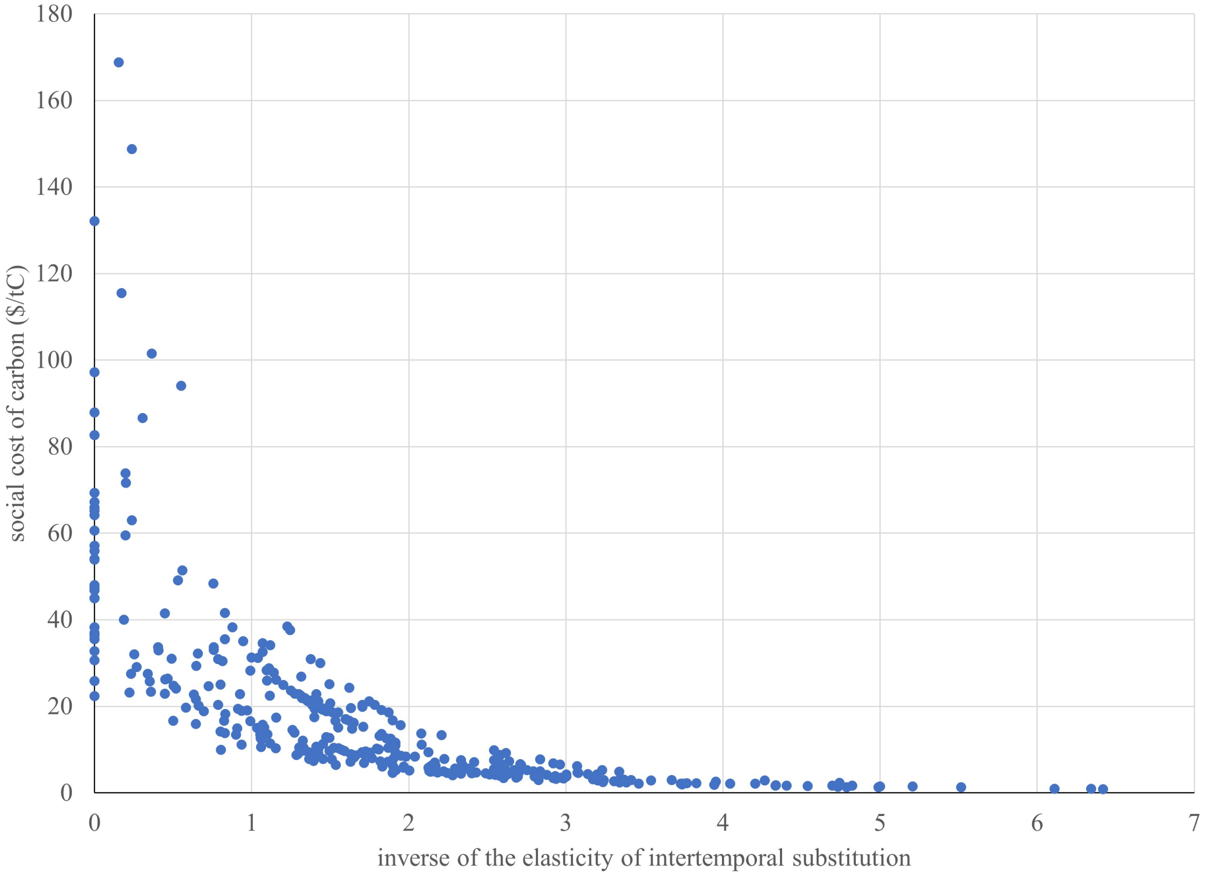


Table B.6: The 2015 global social cost of carbon ($^{2015}) per tonne of carbon) for national time and risk preferences according to four alternative calibrations.

	Falk			Table A.1	
	unweighted	weighted	Eur & NAm	observed	imputed
Afghanistan	10.1	4.7	25.7	20.6	20.6
Algeria	29.3	26.4	54.0	21.2	21.2
Argentina	8.2	3.5	19.7	21.9	20.4
Australia	30.9	13.7	86.6	15.1	20.8
Austria	15.6	4.9	38.3	17.1	20.4
Bangladesh	6.5	2.2	13.9	20.0	20.0
Bolivia	12.9	5.6	33.7	26.1	20.6
Bosnia Herzegovina	5.8	2.1	12.3	20.1	20.1
Botswana	87.9	65.2	69.3	21.9	21.9
Brazil	4.6	1.6	9.1	6.4	19.9
Cambodia	3.9	1.3	7.2	19.6	19.6
Cameroon	2.7	0.9	4.6	19.3	19.3
Canada	37.7	20.3	115.5	18.9	20.9
Chile	10.7	5.0	27.5	22.9	20.6
China	13.6	4.7	33.7	34.6	20.4
Colombia	6.2	2.5	13.8	13.2	20.2
Costa Rica	8.0	3.2	18.8	28.8	20.4
Croatia	9.9	4.2	24.8	20.5	20.5
Czech Republic	13.4	4.6	33.0	28.3	20.4
Egypt	4.0	1.4	7.7	19.8	19.8
Estonia	5.2	1.7	10.3	35.5	19.8
Finland	8.8	2.3	18.6	17.1	20.0
France	12.6	4.4	30.9	22.9	20.4
Georgia	5.2	2.1	11.2	20.1	20.1
Germany	16.8	5.3	41.5	20.7	20.4
Ghana	67.2	47.5	55.9	21.7	21.7
Greece	5.0	1.9	10.4	17.1	20.0
Guatemala	4.8	1.7	9.8	31.2	19.9
Haiti	6.9	2.9	15.9	20.3	20.3
Hungary	2.8	1.0	4.9	25.9	19.4
India	4.9	1.6	9.7	14.8	19.8
Indonesia	3.8	1.3	7.2	19.7	19.7
Iran	14.2	10.0	30.6	2.9	21.0
Iraq	9.0	4.6	23.2	20.6	20.6
Israel	32.6	19.4	97.1	21.0	21.0
Italy	8.4	2.9	19.1	21.3	20.2
Japan	5.0	1.5	9.6	17.5	19.7
Jordan	5.1	2.0	10.6	20.1	20.1
Kazakhstan	12.8	7.4	35.5	20.8	20.8
Kenya	15.8	9.1	44.9	20.9	20.9
Lithuania	7.9	3.0	18.3	49.1	20.3
Malawi	33.0	36.7	46.8	21.3	21.3
Mexico	6.3	2.2	13.5	6.6	20.1
Moldova	10.4	3.7	25.1	20.4	20.4
Morocco	6.1	2.4	13.4	20.2	20.2
Netherlands	38.4	21.2	168.8	18.6	21.0
Nicaragua	2.4	0.9	4.1	27.8	19.2
Nigeria	20.2	16.7	38.2	21.1	21.1
Pakistan	9.0	3.6	21.6	20.4	20.4
Peru	12.0	5.8	32.0	20.3	20.7
Philippines	22.9	15.1	57.1	21.0	21.0
Poland	8.4	3.0	19.4	35.1	20.3
Portugal	2.1	0.7	3.3	16.2	18.9
Romania	4.7	1.7	9.4	19.9	19.9
Russia	4.6	1.5	8.9	71.6	19.8
Rwanda	3.5	1.3	6.5	19.7	19.7
Saudi Arabia	82.6	60.6	66.0	21.8	21.8
Serbia	6.2	2.3	13.5	20.1	20.1
South Africa	64.2	45.0	53.9	22.4	22.4
South Korea	12.5	4.3	30.4	31.3	20.4
Spain	7.9	2.6	17.4	17.1	20.1
Sri Lanka	9.7	4.1	24.1	20.5	20.5
Suriname	14.6	7.3	40.0	20.7	20.7
Sweden	24.3	9.3	94.1	23.7	20.7
Switzerland	19.1	6.2	48.4	20.5	20.5
Tanzania	23.4	22.3	32.8	21.3	21.3
Thailand	5.9	2.2	12.6	20.1	20.1
Turkey	9.4	3.8	22.7	26.9	20.4
Uganda	10.5	5.2	27.5	20.7	20.7
Ukraine	5.1	1.8	10.4	19.9	19.9
United Arab Emirates	10.4	4.5	26.3	20.5	20.5
United Kingdom	19.6	7.3	51.5	16.7	20.6
United States	30.0	13.3	101.5	21.2	20.8
Venezuela	13.4	7.8	37.0	15.3	20.8
Vietnam	10.2	3.8	24.7	20.4	20.4
Zimbabwe	29.1	25.8	36.4	21.4	21.4

Table B.7: The global average social cost of carbon for alternative scenarios.

		Falk		Table A.1		Hofstede
	unweighted	weighted	Eur & NAm	observed	imputed	
SSP1	14.5	5.4	34.2	18.3	16.5	18.9
SSP2	15.4	5.9	31.6	21.8	20.4	19.2
SSP3	18.1	8.2	27.1	29.2	28.7	20.8
SSP4	15.1	5.9	28.9	22.6	21.4	18.3
SSP5	15.4	5.5	40.3	16.6	14.3	21.0

The 2015 social cost of carbon ($\$^{2015}/tC$) is the average of the global social costs of carbon for national time and risk preferences. Averages are unweighted unless indicated otherwise.

Table B.8: The global average social cost of carbon for alternative impact functions.

		Falk		Table A.1		Hofstede
	unweighted	weighted	Eur & NAm	observed	imputed	
Tol (2024b)	9.8	3.8	20.1	13.9	13.0	12.2
Barrage and Nordhaus (2023)	15.4	5.9	31.6	21.8	20.4	19.2
Howard and Sterner (2017)	37.9	14.6	78.0	53.9	50.4	47.3

The 2015 social cost of carbon ($\$^{2015}/tC$) is the average of the global social costs of carbon for national time and risk preferences. Averages are unweighted unless indicated otherwise.

Table B.9: The global average social cost of carbon for alternative income elasticities.

		Falk		Table A.1		Hofstede
	unweighted	weighted	Eur & NAm	observed	imputed	
$\varepsilon = 0.18$	30.9	10.6	68.7	44.5	40.9	40.4
$\varepsilon = 0.00$	24.3	8.7	52.6	34.8	32.2	31.2
$\varepsilon = -0.18$	19.2	7.1	40.6	27.4	25.5	24.4
$\varepsilon = -0.36$	15.4	5.9	31.6	21.8	20.4	19.2
$\varepsilon = -0.72$	10.1	4.2	19.8	14.2	13.4	12.3

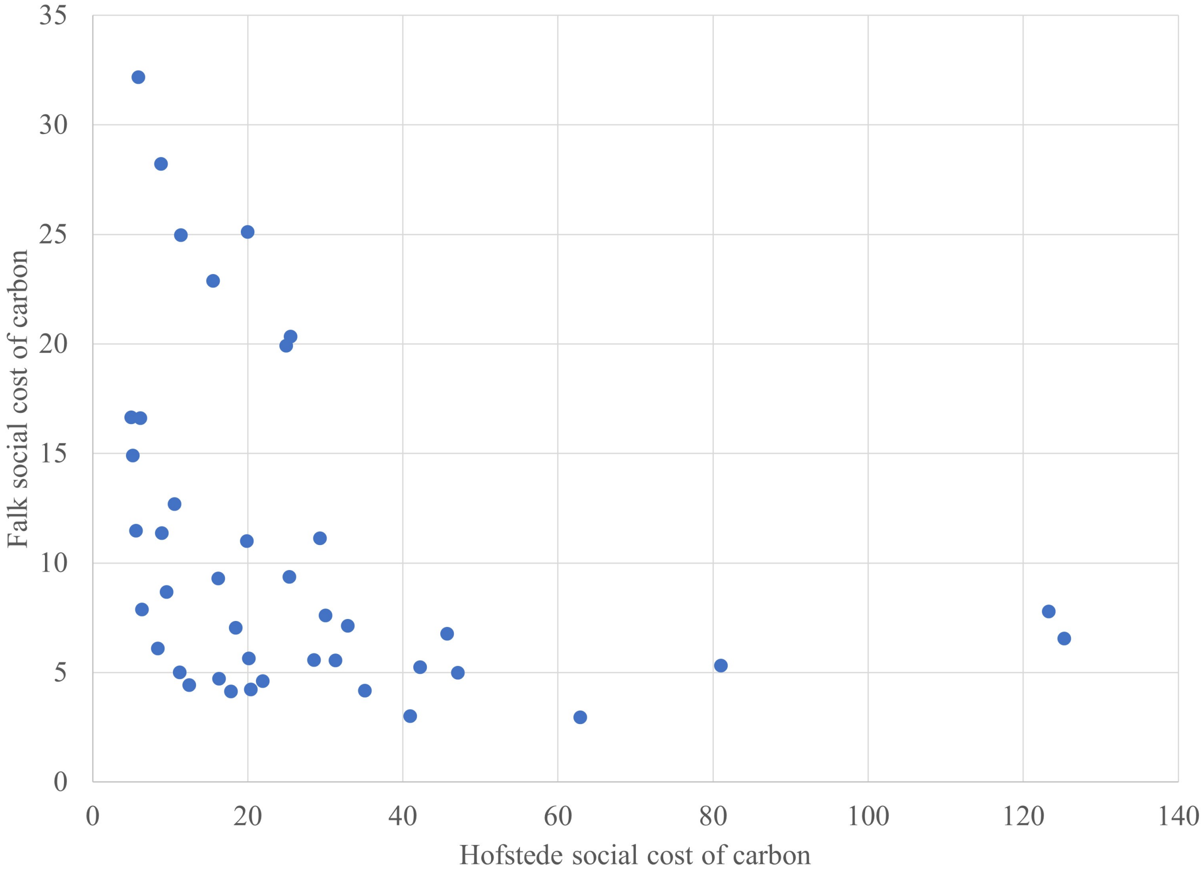
The 2015 social cost of carbon ($\$^{2015}/tC$) is the average of the global social costs of carbon for national time and risk preferences. Averages are unweighted unless indicated otherwise.

Table B.10: Social cost of carbon when preferences are calibrated to Hofstede's cultural dimensions

	LTO	UA	PRTP	RRA	SCC
Argentina	20.40	86.00	3.66	2.59	4.1
Australia	21.16	51.00	3.62	1.12	11.5
Austria	60.45	70.00	1.46	1.91	11.0
Bangladesh	47.10	60.00	2.19	1.50	12.7
Belgium	81.86	94.00	0.28	2.92	6.8
Brazil	43.83	76.00	2.37	2.17	7.0
Bulgaria	69.02	85.00	0.99	2.54	7.5
Canada	36.02	48.00	2.80	0.99	16.6
Chile	30.98	86.00	3.08	2.59	4.6
China	87.41	30.00	0.00	0.24	148.7
Colombia	13.10	80.00	4.06	2.33	4.4
Croatia	58.44	80.00	1.57	2.33	7.6
Czech Republic	70.03	74.00	0.93	2.08	11.1
Denmark	34.76	23.00	2.87	0.00	48.0
El Salvador	19.65	94.00	3.70	2.92	3.4
Estonia	82.12	60.00	0.27	1.50	25.1
Finland	38.29	59.00	2.68	1.45	11.4
France	63.48	86.00	1.29	2.59	6.8
Germany	82.87	65.00	0.22	1.70	20.3
Great Britain	51.13	35.00	1.97	0.45	41.5
Greece	45.34	112.00	2.29	3.67	2.9
Hong Kong	60.96	29.00	1.43	0.20	73.8
Hungary	58.19	82.00	1.58	2.42	7.1
India	50.88	40.00	1.98	0.66	32.2
Indonesia	61.96	48.00	1.37	0.99	28.2
Iran	13.60	59.00	4.04	1.45	7.9
Ireland	24.43	35.00	3.44	0.45	22.9
Israel	37.53	81.00	2.72	2.38	5.6
Italy	61.46	75.00	1.40	2.12	9.4
Japan	87.91	92.00	0.00	2.84	7.8
South Korea	100.00	85.00	0.00	2.54	9.9
Latvia	68.77	63.00	1.00	1.62	16.7
Lithuania	81.86	65.00	0.28	1.70	19.9
Luxembourg	63.98	70.00	1.26	1.91	11.6
Malaysia	40.81	36.00	2.54	0.49	31.0
Malta	47.10	96.00	2.19	3.00	4.3
Mexico	24.18	82.00	3.45	2.42	4.7
Morocco	14.11	68.00	4.01	1.83	6.1
Netherlands	67.00	53.00	1.10	1.20	25.0
New Zealand	32.75	49.00	2.98	1.03	15.0
Norway	34.51	50.00	2.89	1.08	14.9
Pakistan	49.87	70.00	2.04	1.91	9.3
Peru	25.19	87.00	3.40	2.63	4.2
Philippines	27.46	44.00	3.27	0.82	16.6
Poland	37.78	93.00	2.71	2.88	4.2
Portugal	28.21	104.00	3.23	3.34	3.0
Romania	51.89	90.00	1.93	2.75	5.2
Russia	81.36	95.00	0.31	2.96	6.5
Serbia	52.14	92.00	1.92	2.84	5.0
Singapore	71.54	8.00	0.85	0.00	132.1
Slovak Rep	76.57	51.00	0.57	1.12	34.1
Slovenia	48.61	88.00	2.11	2.67	5.3
Spain	47.61	86.00	2.16	2.59	5.5
Sweden	52.90	29.00	1.87	0.20	59.5
Switzerland	73.55	58.00	0.74	1.41	22.9
Taiwan	92.95	69.00	0.00	1.87	18.6
Thailand	31.74	64.00	3.04	1.66	8.7
Trinidad and Tobago	12.59	55.00	4.09	1.29	8.8
Turkey	45.59	85.00	2.28	2.54	5.6
United States	25.69	46.00	3.37	0.91	14.9
Uruguay	26.20	100.00	3.34	3.17	3.2
Venezuela	15.62	76.00	3.93	2.17	5.0
Vietnam	57.18	30.00	1.64	0.24	63.0
Average	49.55	67.17	2.08	1.81	10.0
Weighted average	58.02	50.95	1.61	1.12	22.5
North America	26.75	46.21	3.31	0.92	15.1
Europe	59.27	70.33	1.52	1.93	17.2
Rest of the world	60.23	49.21	1.49	1.04	57.8

The table shows Hofstede's long-term orientation (LTO) and uncertainty avoidance (UA), the calibrated pure rate of time preference (PRTP) and rate of relative risk aversion (RRA), and the resulting estimate of the social cost of carbon (SCC; in dollar per tonne of carbon).

Figure B.4: The social cost of carbon for preferences calibrated to the Hofstede data versus the Falk data



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