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Prices vs. equity in international climate policy: A broad perspective

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Abstract

Effective climate policy can be achieved by implementing either a global uniform carbon price or a global cap and trade system. But depending on the allocation of tax revenues and initial pollution permits, the instruments have very different wealth implications for the individual countries. The paper highlights the distributional effects of climate policies by calculating and comparing emission budget allocations under three different schemes that are in line with a 2 °C warming target. We calculate implicit carbon budgets up to 2050 under a globally uniform CO_2 price, a design proposed by Weitzman (2014). We then compare the allocation with the budget derived from equity principles by Bretschger (2013) and with emission budgets under egalitarian emission rights as proposed by BASIC (2011). Our results show that implicit burden sharing across countries varies substantially with the different policy regimes. Wealthy countries with low energy prices tend to obtain the highest emission budget under a price scheme while poor low-emission countries receive the highest budget under egalitarian emission rights. The budget positions of India and the US are illustrative for the conflicting country interests.

JEL-Classification: Q58, Q53
Keywords: Climate change policy, greenhouse gas emissions, uniform carbon tax, equity principles

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1 Introduction

To mitigate global warming, different instruments for a reduction of greenhouse gas emissions have been proposed. Following the principles of environmental policy, the characteristics and specific effects of these policies have to be assessed and compared. With regard to economic efficiency, it does not matter whether the regulator chooses to influence emission prices or quantities, provided demand and supply functions are known, see (Hepburn, 2006). In case of uncertainty, the choice of the instrument may have allocative effects, see Weitzman (1974) and Stern (2006). In any case, when using a quantity instrument, the regulator implicitly imposes an emission price; vice versa, for every tax regime, an equivalent cap and trade system can be designed. A uniform world carbon price results both from a global carbon tax and a global emission permit market, which can also be constituted by integrated regional cap and trade regimes. But all these considerations only concern efficiency, while in politics, the distributional consequences are at least as important.

The present paper argues that the distributional effects of the different global climate policy proposals are gigantic and thus pivotal for an international agreement. It directly relates to the recently agreed "Lima call for climate action" where in paragraph 3 the commitment has been underscored "to reaching an ambitious agreement in 2015 that reflects the principle of common but differentiated responsibilities and respective capabilities..." and in paragraph 14 that each country will have to explain "how the Party considers that its intended nationally determined contribution is fair and ambitious, in light of its national circumstances, and how it contributes towards achieving the objective of the Convention ..." Responsibility, capability, equity, and fairness are thus confirmed to be important aspects of future climate policy. The concept of "common but differentiated responsibilities" expresses that global public good problems can only be addressed with global partnership (Page, 2008; Stone, 2004). To determine the responsibilites, equity principles can and should be applied.

Given the long-term target of maximum 2 °C warming, Meinshausen et al. (2009) calculate that the probability of warming exceeding 2 °C is less than 50 percent when global carbon dioxide emissions amount to 1440Gt in the period 2000 to 2050. From an efficiency point of view, a carbon price that limits emissions to that budget is efficient. But in terms of distribution the question reads: who gets what share of the global carbon budget? As soon as a carbon price is established, carbon budgets directly translate into the countries' wealth position. For international burden sharing in climate policy it makes a big difference whether we adopt a world carbon tax or an integrated cap-and-trade system, because the distribution of tax revenues and the initial budgets allocations have high distributional impact.

Our paper compares the explicit and implicit CO_2 budget distributions of three different approaches: The uniform tax approach proposed by Weitzman (2014), the equity principle approach put forward by Bretschger (2013), and the egalitarian approach of equal emission rights proposed by BASIC (2011). Specifically, given the global CO_2 budget until 2050 from Meinshausen et al. (2009), we approximate the uniform carbon tax that reduces global emissions in line with the emission target and infer the implied CO_2 budget distribution of that approach. This budget allocation is compared to the one derived by Bretschger (2013) from four basic equity principles. The two distinct regimes are then contrasted with the egalitarian approach of equal access to carbon space, as proposed by BASIC (2011). Interestingly, while many countries are not very differently affected by the policies, we find huge budget differences for India and the US. While India's position is most favorable with the equal access to carbon space, the United States are best off with the carbon tax. We also show various other interesting differences for various countries. With its focal point on distribution, the paper complements other recent findings about different climate policies.

It is evident that many low-income countries contribute little to climate change but are most vulnerable to its effects. The effects of climate change and climate adaptation are biased in favor of the rich countries and to the disadvantage of the less developed (Bretschger and Valente, 2011; World Bank, 2010). This is the reason why climate mitigation is an effective means to avoid increasing inequalities in global wealth distribution. But also climate policy itself is critical for less developed countries. Whichever climate policy is preferred in the end, the CO_2 price must rise globally for a policy that effectively reduces global emissions. In order to incentivize less developed countries to accept higher CO_2 prices, financial support is warranted. Prominently, the Green Climate Fund has been established through which poor countries will receive transfer payments (Cramton and Stoft, 2012). Again, not all the countries are expected to contribute equally to this fund. It is natural to assume that the rich should carry a greater share of the burden, which brings us back to the distributional focus of the present paper.

The remainder of the paper is structured as follows. In Section 2 we illustrate the problem of excess emissions and look at the importance of wealth and prices for emission levels. Section 3 lays out the theoretical assessment of different proposals for international climate policy followed by an assessment of the quantitative effects in Section 4. In Section 4.1 we calculate the implicit carbon budget distribution imposed by a uniform carbon tax, in 4.2 we discuss equity based budgets and replicate the budget calculation of Bretschger's (2013) proposal and subsequently compare these proposals to an egalitarian budget policy. It is done first from a theoretical perspective in Section 4.3, followed by the comparison of the calculated budgets in Section 4.4. In Section 4.5 we weaken a central assumption of Section 4.1 and compare again the distributional consequences of the three climate policy schemes. How the recent emission pledges of China and the US compare to the three climate policy schemes analyzed in this paper is discussed in Section 4.6. Section 5 concludes.

2 Worldwide carbon emissions

To provide a foundation for our comparative carbon budget allocation we start with the analysis of the aggregate budget and its determinants. Meinshausen et al. (2009) calculate that, if worldwide emissions between 2000 and 2050 are limited to 1440 Gt CO_2, the probability of warming exceeding 2 °C is 50%. The available budgets for a 25% and 33% probability are 1000 Gt and 1160 Gt respectively. Henceforth, we refer to these scenarios as the "probability targets". Between 1990 and the end of 2010 global CO_2 emissions rose by 51% from 22.2 Gt to 33.6 Gt and from 2000 to 2010 by 35% from 24.8 Gt to 33.6 Gt according to the World Development Indicator (WDI) database.[1]

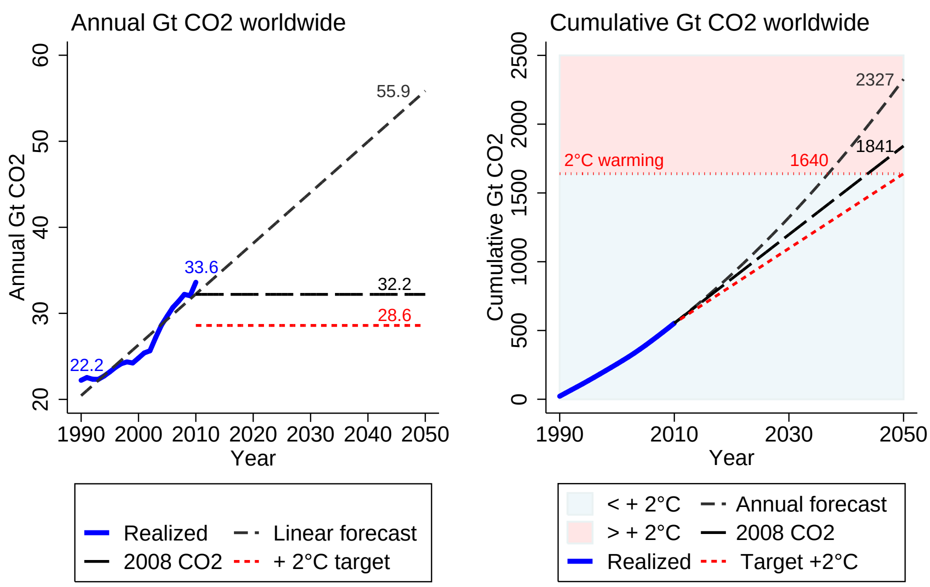


Figure 1: Annual and cumulative worldwide CO_2 emissions, 1990-2050

The blue bold line in the left graph of Figure 1 depicts the global emissions path since 1990 and the dashed line corresponds to the linear forecast

[1] This paper uses exclusively WDI data. `http://data.worldbank.org/data-catalog/world-development-indicators`, visited on May 5, 2014

of global emissions until 2050. Because global carbon emissions amount to roughly 200 Gt between 1990 and 2000, the available emission budget from 1990 to 2050 is 1640 Gt in the 50% probability target. Given the actual emissions until the beginning of 2011, annually 28.6 Gt can be emitted until 2050 to be within target range. This annual budget is represented by the lower horizontal line and is in contrast to the observed worldwide emission dynamics.

As shown in the right graph of Figure 1, the worldwide cumulative emissions based on the linear annual emission forecast are 2327 Gt from 1990 to 2050 and therefore 687 Gt over to 50% probability target. Assuming that emissions are on average stabilized at the 2008 level of 32.2 Gt in the period 2010 until 2050, the cumulative emissions in 2050 are 1841 Gt and in excess of the target by 201 Gt. In order to reach the not so ambitions 50% probability target, global emission reduction efforts are necessary.

The left graph of Figure 2 illustrates that a few countries are of paramount importance for worldwide CO_2 emissions. China and the United States account for 39% of global emissions in 2008. Together with India, Russia, Japan and Germany they account for 57% of global emissions. When all of the 198 country emissions[2] are ranked, only ten countries account for 63% of the global emissions, 20 for 76%, 30 for 83% and the first 61 countries account for over 90% of worldwide emissions. Henceforth, our illustrations and calculations focus on these 61 countries.

A country's carbon emissions are the product of CO_2 emissions per capita and population size. In the right graph of Figure 2 emissions per country are plotted against per capita emissions with circle sizes being proportional to the population of each country. This graph underlines that in 2008 China and India had relatively low per capita CO_2 emissions of 5.3 and 3.1 tons respectively but a large population, whereas the United States had high per capita emissions of 18.6 tons and a medium sized population. Detailed country lists with country ranks and additional information are presented in Table A1 and A2 in the appendix. In Table A1 countries are ranked according to their share at global emissions and in Table A2 countries are ranked according to their per capita CO_2 emissions.

To provide the basis for our policy analysis in the next section we now plot per capita CO_2 emissions against some crucial price and quantity variables, fit linear prediction lines in the data and illustrate the influence of third variables by drawing circles proportional to the targeted variable. The left graph of Figure 3 shows that per capita emissions are positively asso-

[2] WDI provides data for 214 countries. Following Bretschger (2013) we dropped the following countries due to data problems: American Samoa, Channel Islands, Curacao, Guam, Isle of Man, Kosovo, Liechtenstein, Lesotho, St. Martin (French part), Monaco, Northern Mariana Islands, Puerto Rico, San Marino, South Sudan, Sint Maarten (Dutch part), Tuvalu, Virgin Islands (U.S.). Moreover, our sample does not contain Gibraltar and Mayotte because they have been removed from the WDI database

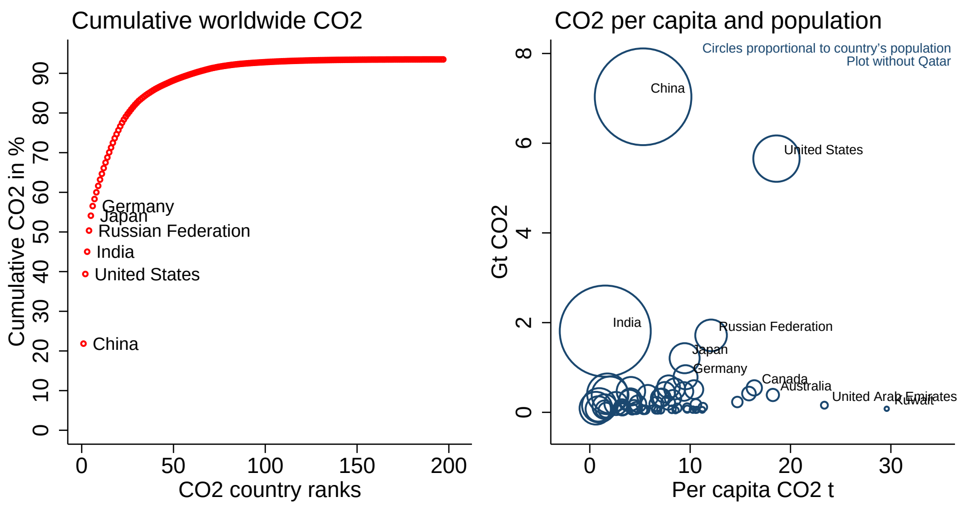


Figure 2: Cumulative worldwide CO_2 emissions (%) and the importance of per capita emissions and population size

ciated with GDP per capita measured in units of 1000 USD. Outliers with high per capita GDP and extremely high emission levels are Qatar (50 t), Kuwait (30 t) and the United Arab Emirates (23 t). At the other side of the spectrum are countries with high per capita GDP and bellow average per capita emissions such as Norway, Denmark, Sweden and the Netherlands. Even though there is a clear-cut positive relationship between wealth, as approximated by GDP per capita, and emission levels, the plot also shows a high degree of variation across countries with similar wealth levels. Similar per capita GDP levels and at the same time substantially different emission levels have for example: Kuwait, United Arab Emirates, United States, Netherlands and Sweden.

The association between per capita CO_2 emissions and fossil energy rents in % of GDP is displayed in the right graph of Figure 3. The fitted regression line in blue shows a positive relationship and the circle sizes, being proportional to GDP per capita, indicate the importance of the wealth level. Countries with high fossil energy rents tend to have higher per capita emissions and more so if per capita GDP is high. Because fossil energy rents are determined by natural endowments, they are exogenous. This graph shows the positive influence of rents from fossil sources on per capita emissions.

Two transmission mechanisms could cause the positive relationship between fossil energy rents and per capita emissions. Either the extraction or production process of fossil energies is very emission intensive or countries with high fossil energy endowments tend to set low prices for fossil energies. Figure 4 addresses the second of these hypotheses. The left graph of Figure

4 illustrates that higher pump gasoline prices are associated with lower per capita emissions. Since the circle sizes are proportional to GDP per capita, it can be seen that the dispersion in per capita emissions for countries with low gasoline prices can be explained by the wealth level differences of those countries. The right graph underlines that countries with high fossil energy rents indeed set substantially lower gasoline prices than countries with low energy rents. The pronounced negative relationship between gasoline price and fossil energy rents seems not systematically influenced by per capita GDP, as the circle sizes capture again GDP per capita.

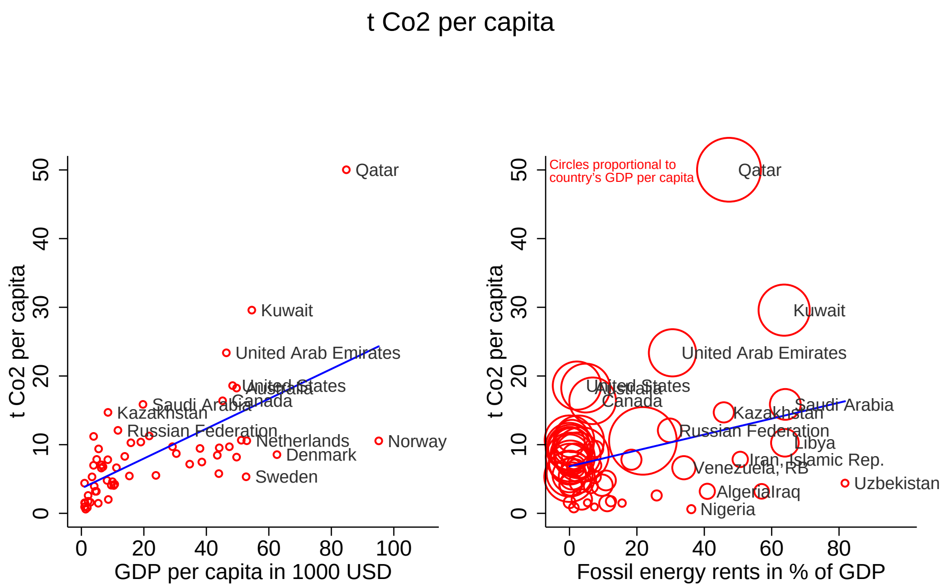


Figure 3: Correlations with t CO_2 per capita

3 Policy analysis

The different proposals for international climate policy have to be evaluated according to their specific characteristics and impacts on different economies. This section presents the theoretical assessment, the next section deals with the quantitative effects. The first considered proposal is to negotiate and impose a single internationally binding minimum carbon price. This is the traditional Pigovian approach in environmental economics which has been recently put forward again by Weitzman (2014). A second set of proposals focuses on emission quantities, that is an internationally harmonized cap-and-trade system with a specific initial allocation of emission permits.

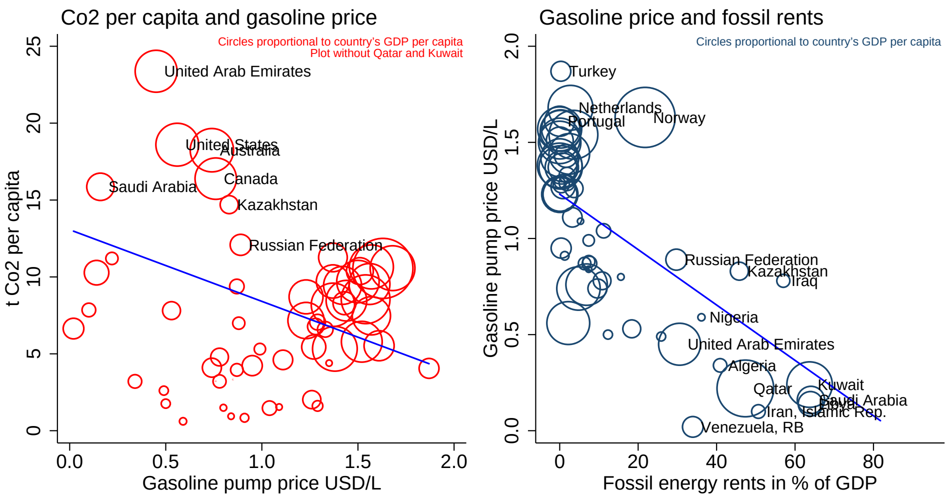


Figure 4: CO_2 and population

Bretschger (2013) develops an initial permit allocation using four broadly accepted equity principles. The plan to base the allocation on a single equity principle, the egalitarian approach, has been proposed by BASIC (2011).

In general, proposed instruments for international climate policies should have several desirable properties. First, the policies have to induce cost effectiveness, which is that emission reduction should be reached at a minimum economic cost. This criterion is obviously fulfilled by both instruments, because a world uniform price emerges both with a Pigovian tax and an internationally harmonized cap-and-trade system; the price ensures the equalization of marginal abatement cost, minimizing total abatement cost according to microeconomic principles.

Second, instruments should provide "natural" focal points to facilitate international climate negotiations. So far, negotiation costs at the conferences of the parties of the UNFCCC have been enormous. The absence of clear focal points for the negotiations raises negotiation costs substantially. A severe constraint is the limited time for further negotiations. As a one-dimensional negotiation target the minimum carbon price satisfies the criterion of focal points in a straightforward manner. On the contrary, if the negotiations over quantities are not following well-specified guidelines but rather concern unspecified quotas for n different national entities, the criterion cannot be fulfilled. However, using broadly accepted equity principles can cure the problem. If parties agree on principles like "ability to pay" like in a national tax context, inital permit can be allocated without too high transaction costs.

Third, the proposed policy should embody a countervailing force against narrow self-interest by incentivizing all negotiating parties to internalize the climate externality. The behavior of the negotiating countries has been studied with the Kyoto agreement, where negotiations about national emission caps were perceived to foster uncooperative self-interested free-riding behavior. Weitzman (2014) argues that negotiations about a global uniform CO_2 price could limit uncooperative behavior as observed in typical public-goods games because the price is a positive argument to the benefit functions of negotiation parties, see also Stiglitz (2006). The positive influence of the price on benefits establishes a countervailing force against uncooperative behavior, under the assumption that tax revenue remains within the countries.

Fourth, international carbon policy should be considered as fair by the negotiating parties, otherwise an agreement cannot be reached. Distributional impact is always an imminent issue in politics but certainly crucial in a world economy that is deeply divided in terms of wealth and pollution history. The implementation of a single internationally binding minimum carbon price from 2020 on ignores any historic responsibilities, that is greenhouse gas emissions prior to that date. With this proposal, the early polluting richer economies get a larger access to world carbon space compared to later developing economies. BASIC (2011) concludes that the same overall carbon budget per capita would be sensible from a worldwide fairness perspective. Weitzman (2014) argues that this would involve massive transfer payments from developed to developing countries. Bretschger (2013) explains that an equal right to atmospheric resources does not consider the macroeconomic context of resource use. The author stresses that, over time, carbon emissions become less important for economic development and human well-being due to technological progress. Therefore, a fair burden sharing involves not an equal access to carbon space but an equal access to sustainable development.

Fifth, taxes and permit systems are not equal in terms of administration and transparency. As regards these more practical aspects of policy implementation, Weitzman (2014) argues that the uniform carbon price outperforms the cap and trade system. However, in both cases, a single international carbon price implies a varying price rate increase on fossil fuels across nations because there are huge national differences in the price level of fossil fuels today. For countries with low prices or fuel subsidies, world carbon policies would have the highest impact. To verify that the effect of a global carbon price is not neutralized by national policies, some international institution would need to monitor energy taxation and subsidy policies across countries. Countries are not homogeneous but consist of different interest groups which have an interest to free-ride within the country's carbon budget. When tax revenues are retained internally they can be used to compensate interest groups or to offset other taxes.

Assessing the different properties, Weitzman (2014) believes that the "'countervailing force property"' is the most important characteristic of an effective climate agreement, favoring the world tax approach. On the contrary, BASIC (2011) and Bretschger (2013) stress the required fairness of international burden sharing, suggesting to apply equity principles for inital permit allocation. In all the cases, efficiency is guaranteed but distributional impact is very different. In the following section we estimate the distributional impacts of price Weitzman (2014), equity (Bretschger, 2013) and egalitarian (BASIC, 2011) schedules quantitatively and compare them.

4 Carbon budget distribution

4.1 Uniform carbon price

We now calculate implicit carbon budgets imposed by a uniform carbon price. To do so, we approximate the uniform carbon price inducing the required worldwide abatement effort to bring global emissions in line with the 50% probability target of Meinshausen et al. (2009). This target states that the remaining global carbon emission budget E_B for the period 2000 to 2050 is 1440 Gt CO_2. Adding the emissions for the period 1990-2000 yields 1640 Gt CO_2. By assuming a business as usual (BAU) emission trajectory for every nation until 2050, the BAU cumulative global emissions can be calculated and therefore the emissions in excess of the 1640 Gt CO_2 target are identified. The uniform carbon price per unit of energy that reduces global emissions by the excess emissions can be derived from average national energy prices, long-run price elasticities of energy demand, and the average carbon content of energy. From that carbon prices demand reductions are obtained using demand elasticities. Demand reductions directly translates into CO_2 reductions, given the BAU emission levels. The implied emission budget of a carbon price is then the difference between the BAU emissions and the abated emissions due to the price increase.

In this section we assume, for simplicity, that emissions for every country stabilize over the period 2009 to 2050 at their 2008, or alternatively, 2010 levels. In section 4.5 we will weaken this assumptions by using emission forecasts from the IEA (2014) if available. Because information about average national energy prices are not available, we posit that pump gasoline prices are representative of energy prices in general, which seems reasonable; we use gasoline prices from 2008 or 2010 as a base year. We further assume that demand elasticities for energy are constant across countries and use three different elasticity levels: -0.5, -0.8 and -1. Based on the literature we favor the elasticity levels ϵ= -0.8 and focus the detailed analysis on this case. According to Flood et al. (2007) the consensus in the literature indeed is that the long-run price elasticity ϵ of gasoline demand is around -0.8 and differences between countries are typically moderate. This elasticity is also in line with Hausman and Newey (1995) and Kilian and Murphy (2013). In order to obtain prices per ton of CO_2 based on the price per unit of energy, in our case gasoline, we use the CO_2 conversion factor for gasoline.

Table 2 shows the country level results based on the demand elasticity $\epsilon = -0.8$ and the 2008 base year for emission levels and gasoline prices. A list of country results for the 2010 benchmark is given in Table A5. We illustrate our calculation in Table 2 with the example of China. The aggregated results in Tables A3 and A4 for different base years can be used in conjunction with the more formal and detailed calculation method explained in section C of the appendix. China had in 2008 a pump gasoline price of 0.99 USD per liter and emitted according to Table A1 7.04 Gt CO_2. Assuming that Chinese emissions from 2009 to 2050 stabilize on average at the 2008 level, China emits during this period roughly 296 Gt. From Table 1 we know that a price rise $\tau = 0.07$ is needed to meet the 50% probability target. This implies for China a tax of 7.4% per liter gasoline and based on the demand elasticity this price increase induces a reduction in energy demand of 5.9%. The demand reduction amounts for the period 2009 to 2050 to 21 Gt CO_2 and reduces cumulative Chinese emissions to 274 Gt.

As a robustness check we made the same calculations using diesel prices and conversion factors instead of gasoline as the energy proxy. This creates a higher tax τ per liter liter and higher carbon prices per ton of CO_2 P_{tCO_2}, but the budget distribution across nations remain very stable. In section 4.5 we will discuss the results for a substantially weaker assumption on emissions.

Table 1: Prices for 2 °C warming with 50% prob.* and different elasticities

		gasoline price & emissions	
Elasticity	**Prices**	**2008 base**	**2010 base**
$\epsilon = -0.5$	τ : CO_2 tax	0.12	0.18
	P_{tCO_2} : Price per t CO_2	50.63	77.30
$\epsilon = -0.8$	τ : CO_2 tax	0.07	0.11
	P_{tCO_2} : Price per t CO_2	31.64	48.31
$\epsilon = -1$	τ : CO_2 tax	0.06	0.09
	P_{tCO_2} : Price per t CO_2	25.31	38.65

*According to Meinshausen et al. (2009), 1440 GT CO_2 can be emitted until 2050. Our sample covers 90% of the worldwide emissions in 2010.

Table 2: Uniform price with base year 2008, +2 °C with 50% probability

Country	Rank	$P_{gasoline}$	% rise $P_{gasoline}$	% reduction D	Gt CO_2 reduction	Gt CO_2 budget
China	1	0.99	7.39	−5.91	−17.05	271.41
United States	2	0.56	13.06	−10.45	−24.23	207.70
India	3	1.09	6.71	−5.37	−3.99	70.28
Russian Federation	4	0.89	8.22	−6.57	−4.62	65.72
Japan	5	1.42	5.15	−4.12	−2.04	47.44
Germany	6	1.56	4.69	−3.75	−1.20	30.91
Iran, Islamic Rep.	7	0.10	73.14	−58.51	−13.69	9.71
Canada	8	0.76	9.62	−7.70	−1.72	20.62
United Kingdom	9	1.44	5.08	−4.06	−0.87	20.55
Korea, Rep.	10	1.51	4.84	−3.87	−0.81	20.02
Mexico	11	0.74	9.88	−7.91	−1.53	17.80
South Africa	12	0.87	8.41	−6.73	−1.28	17.78
Italy	13	1.57	4.66	−3.73	−0.68	17.65
Saudi Arabia	14	0.16	45.71	−36.57	−6.27	10.88
Indonesia	15	0.50	14.63	−11.70	−1.98	14.93
Brazil	16	1.26	5.80	−4.64	−0.74	15.16
Australia	17	0.74	9.88	−7.91	−1.26	14.64
France	18	1.52	4.81	−3.85	−0.59	14.69
Spain	19	1.23	5.95	−4.76	−0.64	12.86
Ukraine	20	0.88	8.31	−6.65	−0.88	12.38
Poland	21	1.43	5.11	−4.09	−0.53	12.43
Turkey	22	1.87	3.91	−3.13	−0.37	11.33
Thailand	23	0.87	8.41	−6.73	−0.72	10.01
Kazakhstan	24	0.83	8.81	−7.05	−0.67	8.78
Malaysia	25	0.53	13.80	−11.04	−0.97	7.78
Egypt, Arab Rep.	26	0.49	14.93	−11.94	−0.96	7.11
Argentina	27	0.78	9.38	−7.50	−0.58	7.21
Venezuela, RB	28	0.02	365.68	−292.54	−22.41	−14.75
Netherlands	29	1.68	4.35	−3.48	−0.25	6.88
United Arab Emirates	30	0.45	16.25	−13.00	−0.85	5.67
Pakistan	31	0.84	8.71	−6.97	−0.45	5.98
Vietnam	32	0.80	9.14	−7.31	−0.38	4.83
Uzbekistan	33	1.35	5.42	−4.33	−0.21	4.71
Czech Republic	34	1.37	5.34	−4.27	−0.20	4.59
Algeria	35	0.34	21.51	−17.21	−0.81	3.89
Belgium	36	1.50	4.88	−3.90	−0.17	4.09
Greece	37	1.23	5.95	−4.76	−0.19	3.82
Romania	38	1.11	6.59	−5.27	−0.20	3.68
Iraq	39	0.78	9.38	−7.50	−0.29	3.58
Nigeria	40	0.59	12.40	−9.92	−0.38	3.42
Kuwait	41	0.24	30.47	−24.38	−0.80	2.48
Korea, Dem. Rep.	42	0.76	9.62	−7.70	−0.25	2.95
Philippines	43	0.91	8.04	−6.43	−0.20	2.91
Chile	44	0.95	7.70	−6.16	−0.18	2.74
Israel	45	1.37	5.34	−4.27	−0.12	2.78
Austria	46	1.37	5.34	−4.27	−0.12	2.68
Qatar	47	0.22	33.24	−26.59	−0.74	2.05
Syrian Arab Republic	48	0.85	8.60	−6.88	−0.19	2.58
Colombia	49	1.04	7.03	−5.63	−0.15	2.57
Belarus	50	1.33	5.50	−4.40	−0.11	2.46
Libya	51	0.14	52.24	−41.79	−1.03	1.44
Portugal	52	1.61	4.54	−3.63	−0.09	2.31
Finland	53	1.57	4.66	−3.73	−0.09	2.23
Turkmenistan	54	0.22	33.24	−26.59	−0.60	1.66
Hungary	55	1.27	5.76	−4.61	−0.10	2.14
Serbia	56	1.29	5.67	−4.54	−0.10	2.03
Bulgaria	57	1.28	5.71	−4.57	−0.10	1.99
Norway	58	1.63	4.49	−3.59	−0.07	1.99
Morocco	59	1.29	5.67	−4.54	−0.09	1.95
Sweden	60	1.38	5.30	−4.24	−0.09	1.93
Denmark	61	1.54	4.75	−3.80	−0.07	1.85

Rank: Country rank in CO2 emissions, $P_{gasoline}$: p/l gasoline in USD, % $P_{gasoline}$ rise: % p/l rise due to tax, % reduction D: Induced demand reduction, Gt CO_2 reduction: Gt CO_2 reduction due to tax, CO_2 budget: New CO_2 budget in Gt

4.2 Equity based budgets

In the study of Bretschger (2013) the global carbon budget is derived from the probability scenarios of (Meinshausen et al., 2009) for the period 2000 to 2050. Effective emissions for the period 1990 to 2000 are added to obtain a world budget starting in 1990, when historic responsibility is assumed to start or, equivalently, the period of "excusable ignorance" is assumed to stop. Emissions between 1990 and the current state are deducted from the overall carbon budget, possibly with a discount, depending on the valuation of historic responsibility. Budgets for each country are calculated using several equity principles: The ability to pay principle, the cost sharing principle, the desert principle, and the polluter pays principle. Moreover, it is reflected that carbon emissions should be evaluated with respect to the technical opportunities available at the time of emission. Specifically, the ability to pay principle is operationalized by using the inverse of income per capita, the distribution of abatement costs by emissions per capita, and the desert principle by the provision of carbon saving technologies. Together with an index for technology development, each principle is equally weighted to create an index for the carbon budget.

We replicate the results of Bretschger (2013) and present country level carbon budgets in a modified manner[3]. Table 3 shows total CO_2 country budgets for the 50% probability target of Meinshausen et al. (2009). Following Table 2 in Bretschger (2013) we apply different "responsibility" factors $0 < \theta \leq 1$ for the effective emissions from 1990 to 2008 to calculate the budgets. The 61 most important emitters are listed in Table 3 (as Table A1) that account together for over 90% of worldwide emissions in 2008. Discounting the emitted emissions by different discount factors establishes for every country a range of budget allocations defined by the extreme values $\theta = 1$ and $\theta \to 0$.

4.3 Theoretical comparison

The discussed budget allocation schemes defined by (i) a uniform price, (ii) an egalitarian distribution, or (iii) the application of equity principles can be conveniently compared in a single diagram. The three schemes yield distinct functional forms expressing per capita budget allocations as a function of current per capita emissions. For simplicity, we abstract from historic responsibility and posit that the total budget does not exceed the optimum carbon budget. Assuming a uniform world carbon price and a constant price elasticity of CO_2 demand, the emissions budget is monotonically increasing in per capita emission levels. Under an equity scheme as proposed by

[3]Our results differ slightly from Bretschger (2013) because we use newer WDI data with a slightly different country coverage: Gibraltar and Mayotte have been removed from the WDI database. Gibraltar's population has fallen below 30,000 and Mayotte became an overseas department of France on March 3, 2011

Table 3: Equity principles, +2 °C with 50% probability

	Gt CO_2 budgets with different discount factors θ			
Country	$\theta \to 0$	$\theta = 0.5$	$\theta = 0.8$	$\theta = 1$
China	265.99	277.75	286.87	294.15
United States	91.86	64.02	42.42	25.17
India	158.51	175.64	188.92	199.53
Russian Federation	46.61	40.71	36.12	32.47
Japan	37.10	33.78	31.21	29.16
Germany	24.49	21.79	19.70	18.03
Iran, Islamic Rep.	15.26	14.93	14.68	14.48
Canada	9.79	7.38	5.51	4.02
United Kingdom	17.18	15.65	14.47	13.53
Korea, Rep.	12.81	11.71	10.86	10.19
Mexico	21.27	21.76	22.15	22.46
South Africa	10.85	9.66	8.73	7.99
Italy	16.16	15.32	14.66	14.14
Saudi Arabia	5.76	4.28	3.13	2.21
Indonesia	33.84	37.26	39.92	42.04
Brazil	30.35	32.98	35.03	36.66
Australia	6.11	4.49	3.23	2.22
France	15.99	15.55	15.20	14.93
Spain	10.87	10.43	10.08	9.81
Ukraine	14.81	14.02	13.41	12.92
Poland	11.13	10.36	9.77	9.29
Turkey	12.81	13.32	13.71	14.03
Thailand	13.07	13.71	14.21	14.61
Kazakhstan	5.09	4.49	4.02	3.65
Malaysia	5.08	4.88	4.73	4.61
Egypt, Arab Rep.	11.75	12.68	13.41	13.99
Argentina	8.00	8.21	8.38	8.51
Venezuela, RB	5.62	5.33	5.10	4.92
Netherlands	4.67	4.10	3.66	3.31
United Arab Emirates	0.81	0.25	−0.19	−0.54
Pakistan	18.73	20.98	22.73	24.12
Vietnam	10.92	12.26	13.30	14.13
Uzbekistan	5.38	5.36	5.34	5.32
Czech Republic	3.29	2.84	2.48	2.20
Algeria	6.14	6.42	6.63	6.80
Belgium	3.11	2.74	2.44	2.21
Greece	2.96	2.76	2.60	2.48
Romania	5.83	5.92	6.00	6.05
Iraq	4.34	4.44	4.51	4.57
Nigeria	15.00	16.94	18.43	19.63
Kuwait	0.79	0.50	0.28	0.10
Korea, Dem. Rep.	5.69	5.43	5.23	5.08
Philippines	10.66	11.91	12.87	13.65
Chile	3.17	3.28	3.37	3.44
Israel	1.49	1.28	1.12	0.99
Austria	2.24	2.09	1.97	1.87
Qatar	0.24	−0.01	−0.21	−0.36
Syrian Arab Republic	2.99	3.09	3.17	3.24
Colombia	6.59	7.20	7.67	8.05
Belarus	2.75	2.69	2.65	2.62
Libya	1.32	1.17	1.05	0.96
Portugal	2.62	2.61	2.60	2.59
Finland	1.57	1.37	1.21	1.09
Turkmenistan	1.11	1.00	0.92	0.85
Hungary	2.73	2.71	2.70	2.69
Serbia	2.11	2.03	1.97	1.92
Bulgaria	2.33	2.30	2.27	2.25
Norway	1.25	1.16	1.08	1.02
Morocco	4.61	5.09	5.46	5.75
Sweden	2.30	2.26	2.23	2.21
Denmark	1.58	1.41	1.28	1.18

Using the cumulated emissions from 1990-2008 divided by population in 1990 to calculate the fairness index.

Bretschger (2013), the budget allocation is determined by a concave function of current per capita emissions. Under an egalitarian approach, the emission budget is independent of per capita emission values.

These relationships are illustrated graphically in Figure 5. Low current per capita emissions result in higher emission budgets under an egalitarian distribution compared to the price scheme. On the other hand, high per capita emissions result in lower emission budgets under an egalitarian compared to a price scheme. Importantly, the graph makes clear that the equity-based approach is in fact a compromise between the extreme cases of the egalitarian and the uniform price approach.

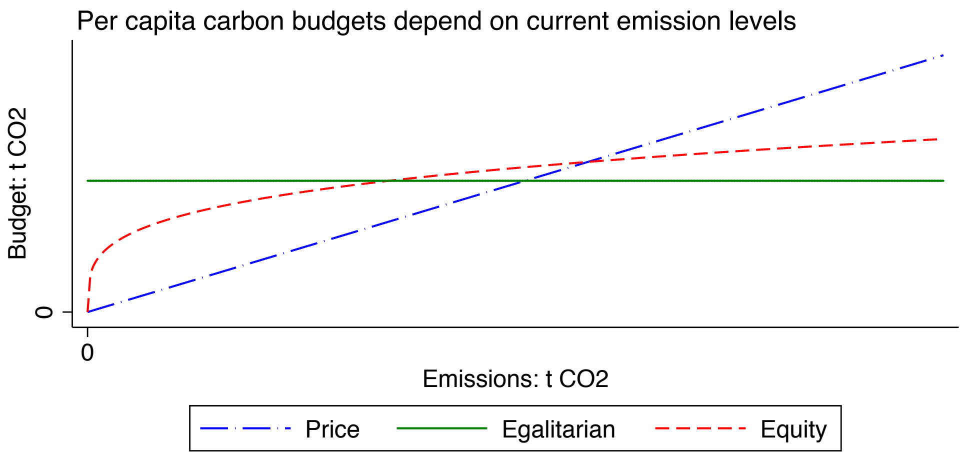
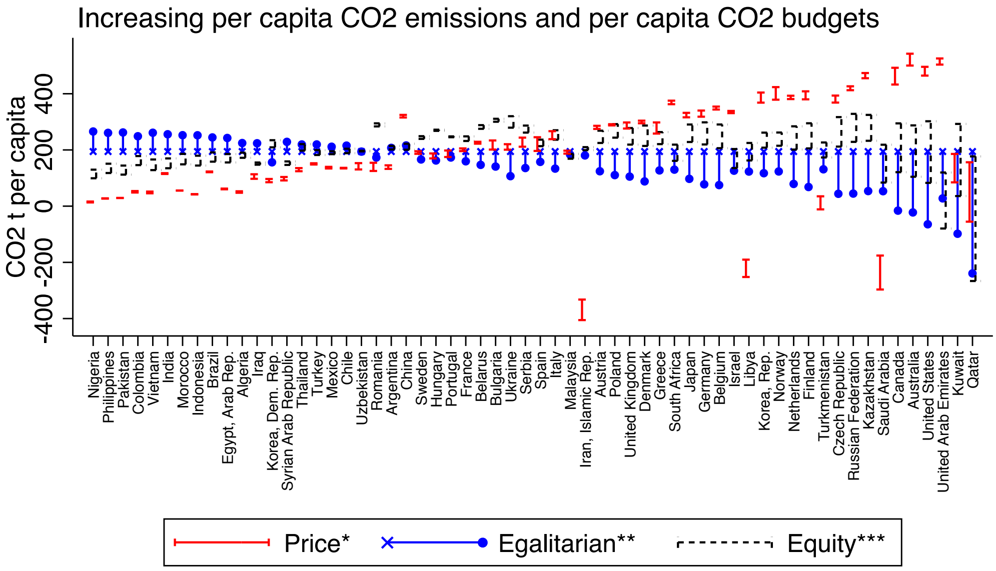


Figure 5: Carbon budgets and current emissions

To illustrate how the basic characteristics of the schematic Figure 5 correspond to the calculated emission budget ranges discussed in the next section 4.4, we sort our country sample according to increasing per capita emissions and plot the per capita budget ranges under the three allocation schemes in Figure 6.



Global carbon budget until 2050 (Meinshausen et al., 2009) is allocated based on 3 approaches (Venezuela is excluded):
* Price: Implicit budget range from a uniform carbon tax as proposed by Weitzman (2014). The estimation assumes a demand elasticity of -0.8 and that gasoline pump prices are representative of energy prices. BAU emissions from 2009 to 2050 are assumed to stabilize at a certain level. Except for China, United States, India, Russian Federation, South Africa, Mexico and Brazil the emission forecasts from IEA are used. The budget range arises because emission levels and gasoline pump prices from 2008 and 2010 are employed in two scenarios.
** Egalitarian: Every person receives the same share of the global budget. Population numbers are from 2008 and different responsibility starting dates are plotted; x - responsibility starts in 2008. • - responsibility starts in 1990.
*** Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013). The range arises from using different discount factors different (theta 0 and 1) for realized emission between 1990 and 2008.

Figure 6: Calculated budget allocation and per capita emissions

4.4 Budget comparison

Emission budgets across countries can be compared on two levels: The country level and the per capita level. When emissions have a price, emission budgets can also be expressed in monetary budgets, which makes the distributional aspect more explicit. The country level budget allocation is relevant from the perspective of real politics because it mirrors the countries' interests. The per capita budget allocation compares similar units and allows therefore for an analytical budget comparison across countries.

The carbon budget allocations for the period 2009 to 2050 vary substantially under different climate policy schemes. We compare approximated budget ranges spanned by the 2008 and 2010 benchmark scenario for the uniform price scheme (Weitzman, 2014) with Bretschger's (2013) equity principles scheme characterized by the discount factor extremes $\theta \to 0$ and $\theta = 1$. To complement the comparison we calculate budget allocations based on egalitarian emission rights with responsibility starting either in 1990 or 2008. By subtracting the global emissions between 2000 and 2008 from the 50% probability budget of Meinshausen et al. (2009) and distributing the remaining balance according to worldwide population shares in 2008, we obtain the egalitarian budget with responsibility starting in 2008 and label it "2008 responsibility" scenario. In the "1990 responsibility" approach we add global emissions from 1990 to 2000 to the 50% probability budget, distribute the global budget according to 2008 population shares and subtract from each country budget the effective country emissions between 1990 and 2008. A budget range for the egalitarian approach is hence spanned by the "1990 responsibility" and "2008 responsibility" approach.

In Figure 7 budget ranges for the price- (Weitzman, 2014), the egalitarian- (BASIC, 2011) and the equity scheme (Bretschger, 2013) are graphically illustrated for the biggest eight emitters worldwide. Figure 8 expands the respective country sample to the 61 countries examined in this paper. Figure 7 shows that the budget ranges for China are for all three approaches quite similar. We find the most substantial budget deviations for the US and India. Whereas the budget differences between China and India are small for the egalitarian approach - both countries have over 1 billion inhabitants - they are substantial for the price and the equity approach. Even though both countries are populous and have gasoline prices of roughly 1 USD per liter, the fact that China's CO_2- and GDP per capita are more than triple those of India account for this difference. Compared with the price and equity allocation India gets a very high egalitarian budget because it is so populous. Its budget according to equity principles is lower because this approach balances the egalitarian principle with other principles such as technology contribution. India's approximated budget under a uniform tax is very low compared to the other approaches and contrasts with the Chinese results. This is driven by India's very low current emissions for its sizable population. The relative budgets ranges for the US show the opposite pattern than India's. The budget under a uniform price is most advantageous for the US because the country's emissions are very high for the population and its gasoline price, 0.56 USD per liter, is at the lower end. The very high US per capita emissions result in a negative budget for the "1990 responsibility" egalitarian approach, as shown by the blue dot in the egalitarian range plot.

The budget rankings for Russia, Japan, Germany, and Canada are very similar. All these countries have the highest implicit budget under a uniform price and the lowest budget allocation is obtained in the egalitarian scheme. The equity scheme sets the middle course between these two extremes. With a few exceptions, this holds also for Figure 8, which underlines that poor countries with low per capita emissions are much better under an egalitarian approach than under a uniform carbon price. Such countries are for example Indonesia, Brazil, Pakistan, Vietnam, Nigeria, and the Philippines. Venezuela has a negative budget under a uniform price because its gasoline price is extremely low. The tax τ of 0.09 USD per liter translates into a price increase of 440% for Venezuela. Given the assumed price elasticity of -0.8 this translates into a demand reduction higher than 100 percent. This illustrates the shortcomings of our calculation for some outlier cases, but we belief that on average our approach is roughly right.

We transform these country level emission budgets into monetary budgets by using an average CO_2 price[4] per ton in Figure 9 and 10. This monetary representation stresses the substantial distributional differences of distinct climate policy schemes. The difference in the allocation of different schemes amounts to thousands of billions of US dollars.

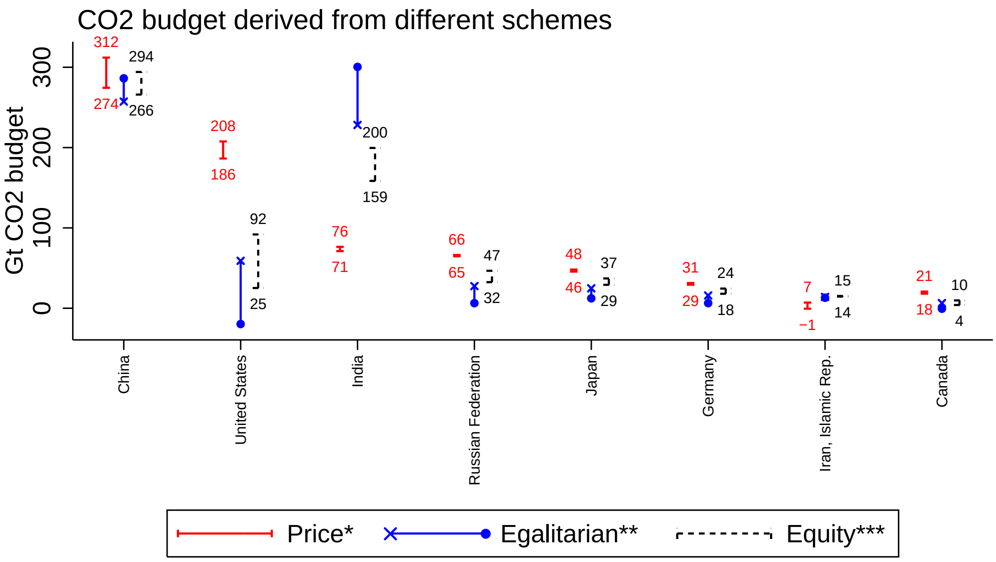
Figures 7 and 8 relate closely to Figures 9 and 10, because they are only scaled differently and have therefore gigatons (Gt) of CO_2 and respectively billion USD on the ordinate axis. So far, the budget allocation comparisons were meaningful within countries but not necessarily between countries due to different population sizes. Therefore, we continue with a per capita comparison.

Figures 11 and 12 depict per capita CO_2 budget allocations in the considered climate policy schemes across countries. This allows for a better comparison between countries. Under the egalitarian approach with responsibility starting in 2008 - the blue cross at the edge of the egalitarian budget range - each country receives 194.2 tons CO_2 per capita for the period 2009 to 2050. When responsibility starts in 1990 - the blue dot in the graph - countries with high per capita emissions have already exceeded their budget until 2050 in 2009, resulting in a negative budget. Even though budget rankings for every country in Figures 11 remain the same as in Figure 7, the budgets are now better comparable across countries. The implied per capita

[4] The mean of P_{tCO_2} in Table 1 for the -0.8 demand elasticity case.

budget based on a uniform price is about ten times higher for the US than for India and about three times higher than for China. Also other energy guzzling countries such as Canada, Australia, Kuwait and Qatar receive very high budgets under a price regime while having negative egalitarian “1990 responsibility” budgets. As before, the budget allocation under equity considerations constitutes the compromise between the price and egalitarian scheme in most cases.

Figures 13 and 14 express the per capita emission budgets in per capita monetary assets. Under a price scheme richer countries tend to get substantially more assets than poor countries. Rich energy inefficient countries receive high asset allocations under a price scheme. The US and Canada receive around 30000 USD per capita, Qatar obtains 60000 USD and India gets around 3000 while China receives about 10000 USD. The monetary equivalent of the equity allocation for the US, India, and China is not very different with 9000, 7100 and 9900 USD respectively. More than an equivalent of 10000 USD per capita are allocated to: India, Indonesia, Brazil, Egypt, Pakistan, Vietnam, Nigeria, Philippines, Colombia and Morocco.



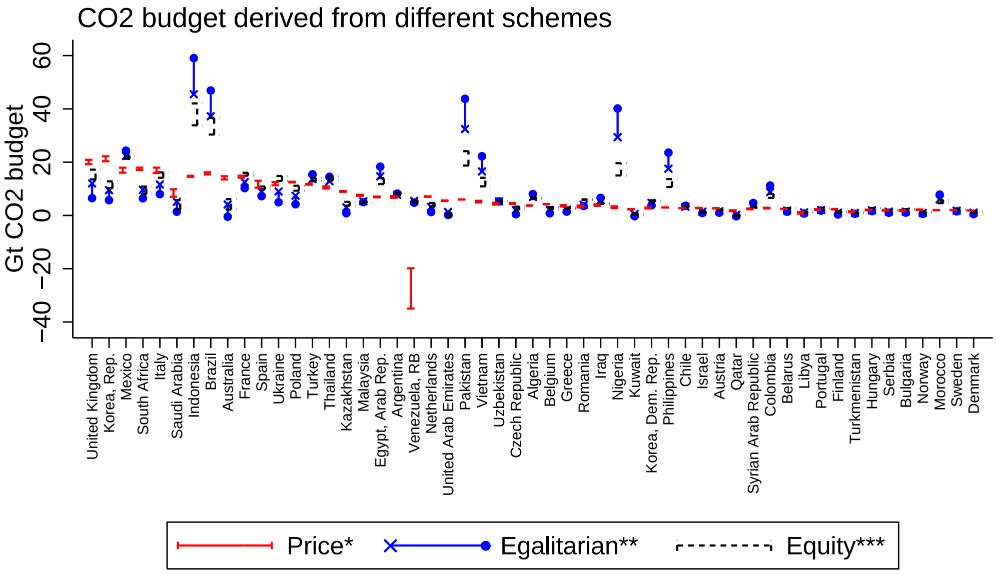
Global carbon budget until 2050 (Meinshausen et al., 2009) is allocated based on 3 approaches:

* Price: Implicit budget range from a uniform carbon tax as proposed by Weitzman (2014). The estimation assumes a demand elasticity of −0.8 and that gasoline pump prices are representative of energy prices. BAU emissions from 2009 to 2050 are assumed to stabilize at a certain level. The budget range arises because emission levels and gasoline pump prices from 2008 and 2010 are used.

** Egalitarian: Every person receives the same share of the global budget. Population numbers are from 2008 and different responsibility starting dates are plotted; × − responsibility starts in 2008. ● − responsibility starts in 1990.

*** Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013). The range arises from using different discount factors different (theta 0 and 1) for realized emission between 1990 and 2008.

Figure 7: Budget ranges derived from uniform tax, egalitarian approach, and equity principles



Global carbon budget until 2050 (Meinshausen et al., 2009) is allocated based on 3 approaches:
* Price: Implicit budget range from a uniform carbon tax as proposed by Weitzman (2014). The estimation assumes a demand elasticity of −0.8 and that gasoline pump prices are representative of energy prices. BAU emissions from 2009 to 2050 are assumed to stabilize at a certain level. The budget range arises because emission levels and gasoline pump prices from 2008 and 2010 are used.
** Egalitarian: Every person receives the same share of the global budget. Population numbers are from 2008 and different responsibility starting dates are plotted; × − responsibility starts in 2008. ● − responsibility starts in 1990.
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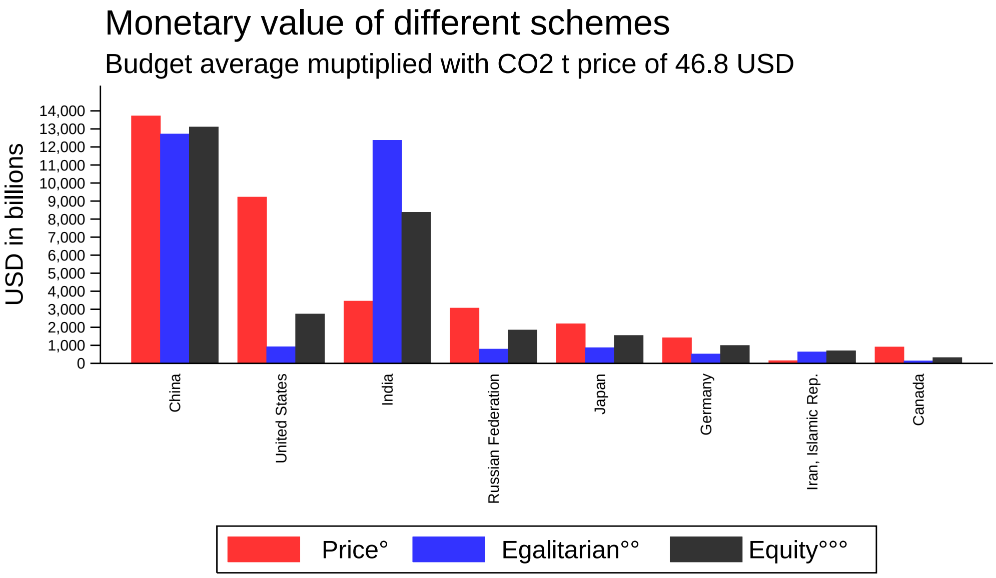
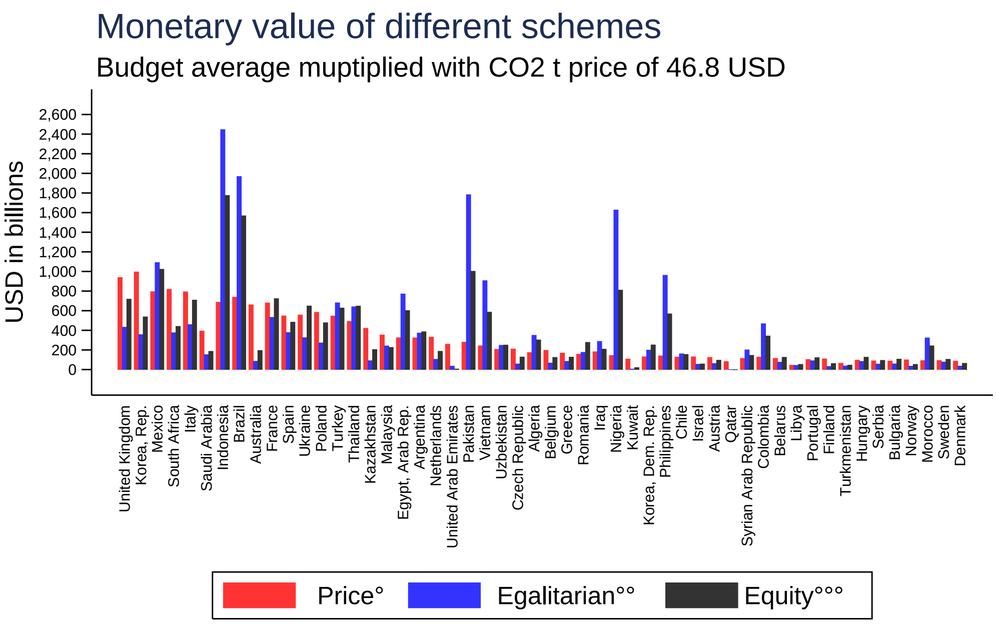
Figure 8: Budget ranges derived from uniform tax, egalitarian approach, and equity principles



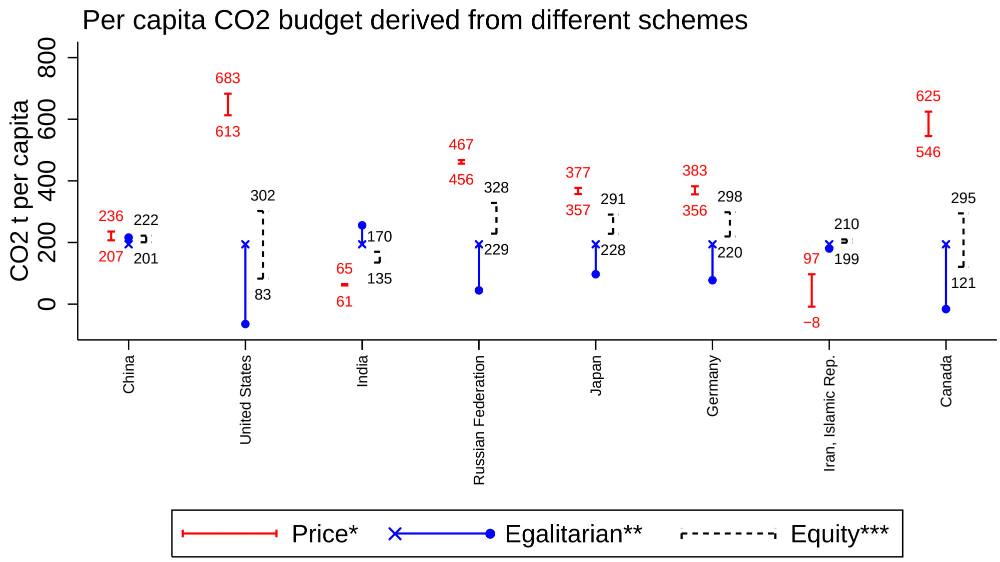
* The average of the previously calculated carbon budget allocations until 2050 for each of the three schemes is multiplied with the average value of a ton CO2 when the demand elasticity is −0.8. CO2 t price = (38.2+55.4)/2 = 46.8.
° Price: Approximated implicit budget resulting from a uniform carbon tax as proposed by Weitzman (2014).
°° Egalitarian: Every person receives the same share of the global budget until 2050.
°°° Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013).

Figure 9: Monetary value of carbon budgets under different regimes



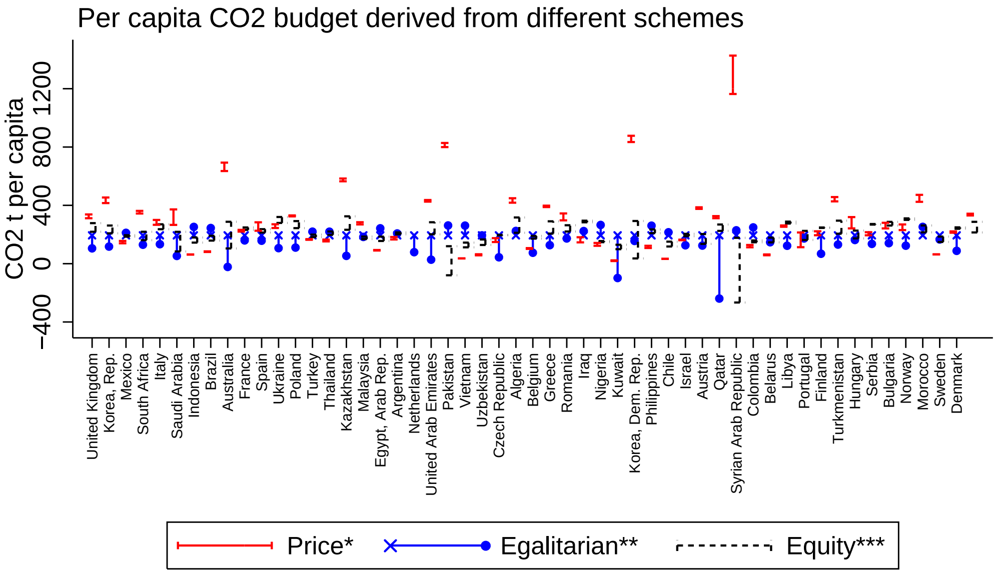
* The average of the previously calculated carbon budget allocations until 2050 for each of the three schemes is multiplied with the average value of a ton CO2 when the demand elasticity is −0.8. CO2 t price = (38.2+55.4)/2 = 46.8. Venezuela is excluded.
° Price: Approximated implicit budget resulting from a uniform carbon tax as proposed by Weitzman (2014).
°° Egalitarian: Every person receives the same share of the global budget until 2050.
°°° Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013).

Figure 10: Monetary value of carbon budgets under different regimes



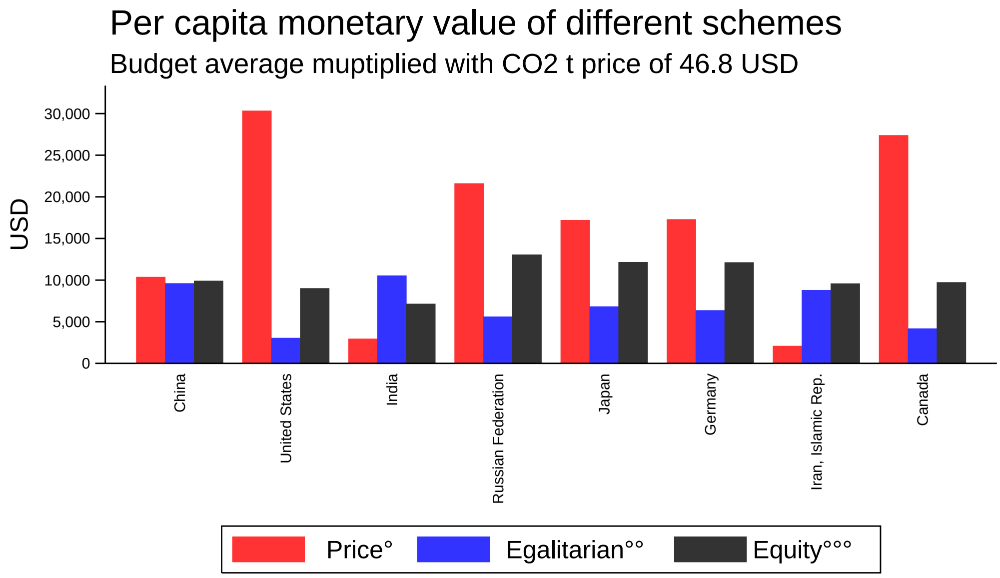
Global carbon budget until 2050 (Meinshausen et al., 2009) is allocated based on 3 approaches:
* Price: Implicit budget range from a uniform carbon tax as proposed by Weitzman (2014). The estimation assumes a demand elasticity of −0.8 and that gasoline pump prices are representative of energy prices. BAU emissions from 2009 to 2050 are assumed to stabilize at a certain level. The budget range arises because emission levels and gasoline pump prices from 2008 and 2010 are used.
** Egalitarian: Every person receives the same share of the global budget. Population numbers are from 2008 and different responsibility starting dates are plotted; × − responsibility starts in 2008. ● − responsibility starts in 1990.
*** Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013). The range arises from using different discount factors different (theta 0 and 1) for realized emission between 1990 and 2008.

Figure 11: Per capita budget ranges derived from uniform tax, egalitarian approach, and equity principles



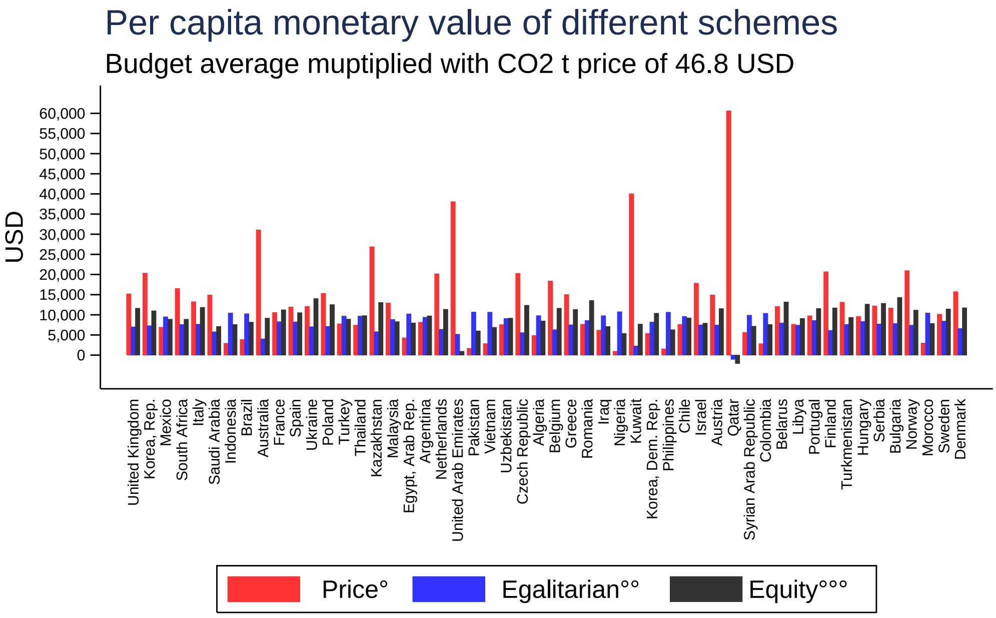
Global carbon budget until 2050 (Meinshausen et al., 2009) is allocated based on 3 approaches (Venezuela is excluded):
* Price: Implicit budget range from a uniform carbon tax as proposed by Weitzman (2014). The estimation assumes a demand elasticity of −0.8 and that gasoline pump prices are representative of energy prices. BAU emissions from 2009 to 2050 are assumed to stabilize at a certain level. The budget range arises because emission levels and gasoline pump prices from 2008 and 2010 are used.
** Egalitarian: Every person receives the same share of the global budget. Population numbers are from 2008 and different responsibility starting dates are plotted; × − responsibility starts in 2008. • − responsibility starts in 1990.
*** Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013). The range arises from using different discount factors different (theta 0 and 1) for realized emission between 1990 and 2008.

Figure 12: Per capita budget ranges derived from uniform tax, egalitarian approach, and equity principles



* The average of the previously calculated carbon budget allocations until 2050 for each of the three schemes is multiplied with the average value of a ton CO2 when the demand elasticity is −0.8. CO2 t price = (38.2+55.4)/2 = 46.8.
° Price: Approximated implicit budget resulting from a uniform carbon tax as proposed by Weitzman (2014).
°° Egalitarian: Every person receives the same share of the global budget until 2050.
°°° Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013).

Figure 13: Per capita monetary value of carbon budgets under different regimes



* The average of the previously calculated carbon budget allocations until 2050 for each of the three schemes is multiplied with the average value of a ton CO2 when the demand elasticity is −0.8. CO2 t price = (38.2+55.4)/2 = 46.8. Venezuela is excluded.
° Price: Approximated implicit budget resulting from a uniform carbon tax as proposed by Weitzman (2014).
°° Egalitarian: Every person receives the same share of the global budget until 2050.
°°° Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013).

Figure 14: Per capita monetary value of carbon budgets under different regimes

4.5 Using IEA emission forecasts

We assumed in Subsection 4.1 that under BAU each country's emissions stabilize at either their 2008 or 2010 level in the period 2009 to 2050. This assumption can be seen as inappropriate for poor low emission countries, whose emissions will likely rise due to rapid economic development. Emission forecasts until 2050 are available from IEA (2014) for several areas (World, OECD, non OECD, ASEAN, European Union) and the following seven countries: China, Unites States, India, Russian Federation, South Africa, Mexico and Brazil.

In this section we use the predicted BAU emissions until 2050 for these countries which corresponds to a six degrees warming scenario. We integrate these emission forecasts in the implied emission budget calculation as a robustness check. For the other countries in our sample we continue to assume constant emission paths. When we assume constant 2008 emissions and integrate the available IEA forecasts, the cumulative emissions between 1990 and 2050 amount to 2210 Gt CO_2. This amount is close to our cumulative emission forecast of 2327 Gt CO_2 from Figure 1. The forecasts with the most extreme emission trajectories in Figure 15 are those of India and China. The emissions for these countries are expected to grow by 252 and 179 percent, whereas the US emission grow 13 percent.

In our previous calculations (Table A3 and A4), a price shock had to reduce excess emissions by either 152 Gt or 202 Gt. For the current scenario excess emissions of either 546 Gt or 549 Gt CO_2 must be reduced by a uniform carbon price as indicated in Tables B7 and B8. Consequently, the uniform carbon tax τ and hence the price per ton of carbon dioxide P_{tCO_2} is higher. This can be seen by comparing Table B9 to Table 2. The country list with the price increases, the demand reaction and the implied budgets under an uniform tax when accounting for emission forecasts is presented in Table B10 for the 2008 base year and in Table B11 for the 2010 base year. Due to the higher tax, countries with less BAU emission growth receive a lower implied budget and countries with relatively low energy prices will abate more emissions in the price scheme due to a higher tax rate. This can be seen in Figures 16 and 17. India obtains now double and China one and a half times the budget than before, whereas the US budget is substantially reduced. Although China and the US favor a price scheme, India still opposes it because it receives the lowest allocation under this scheme. The negative budget for Venezuela is increased due to the higher CO_2 price and Saudi Arabia has now also a negative implied budget under a price scheme due to its low gasoline price of 0.16 USD per liter.

The monetary equivalents of these budgets in Figures 18 and 19 are markedly higher than before because the average price for a ton of CO_2 is due to higher excess emissions two and a half times higher. Therefore, the difference in emission allocations based on distinct climate policy schemes translate for the three biggest emitters - China, US, and India - to ten thousands of billions USD.

Looking at the per capita emission budgets in a the price scheme, Figures 20 and 21 show that China's budget is about 40 and India's two hundred percent higher than before. Under a price scheme the per capita US budget is now four times higher than India's and one and a half times higher than China's. Russia's budget is slightly smaller in the price regime as is Iran's due to a low gasoline price of 0.1 USD per liter.

Figures 22 shows that not only the US, Russia, Japan, Germany, and Canada but also China obtain the highest asset allocation under a price scheme. On the other hand, India and Iran are worst off under a price scheme. Figure 23 also supports the identified pattern before that wealthy countries, provided that they do not have low energy prices, tend to get the highest asset allocation under a price scheme. Qatar for example obtains a negative budget because it's gasoline price is 0.22 USD per liter, so that a uniform price of 0.27 USD per liter produces in conjunction with a demand elasticity of -0.8 a reduction of 108 percent.

Overall, the distributional differences of the three analyzed climate policy schemes are even more pronounced than before, driven essentially by the higher carbon tax τ. While the relative differences between the egalitarian and the equity scheme remain constant, they change for the price scheme.

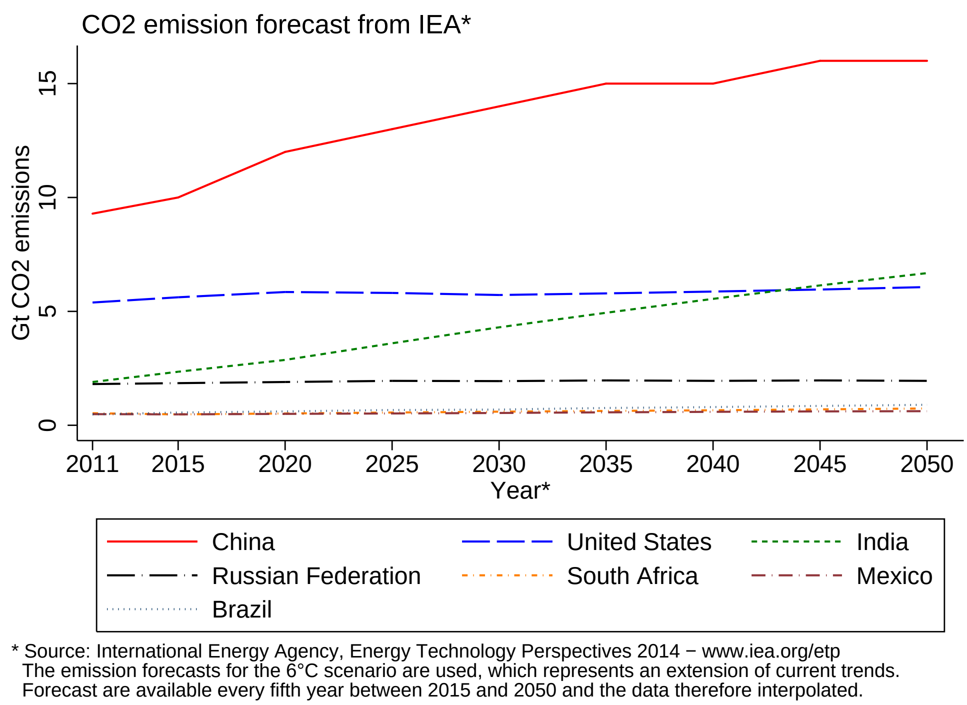
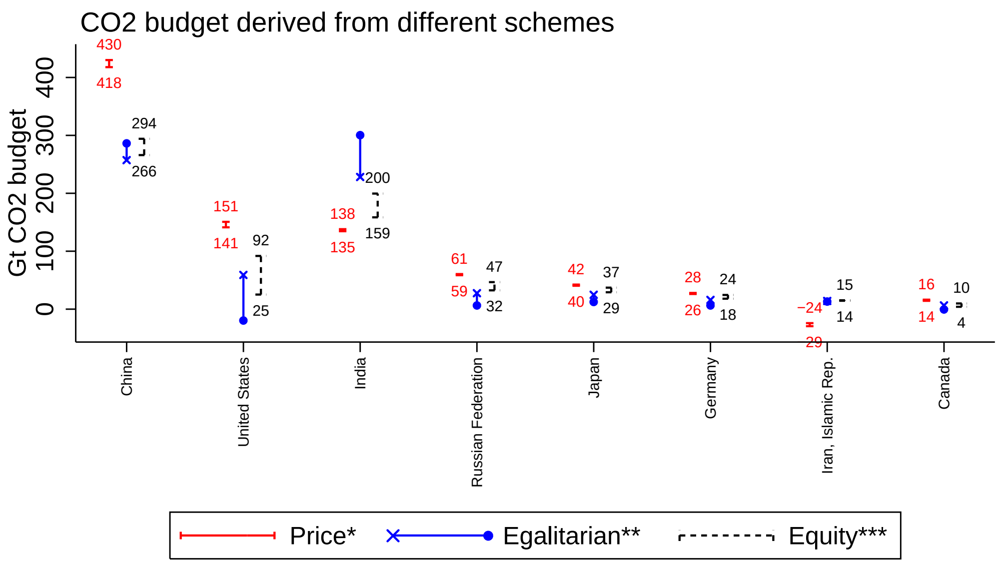
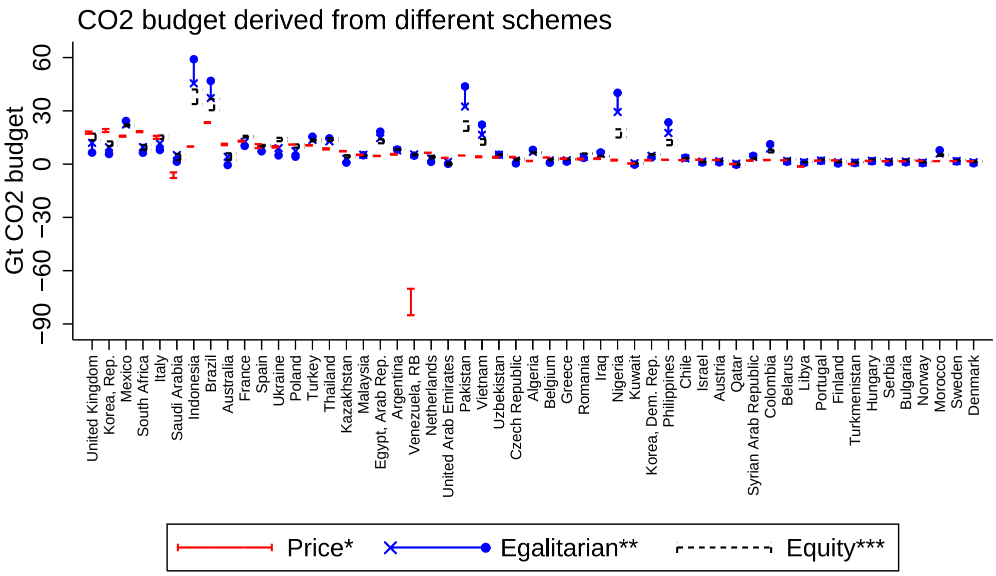


Figure 15: Emission forecast for some countries



Global carbon budget until 2050 (Meinshausen et al., 2009) is allocated based on 3 approaches:
* Price: Implicit budget range from a uniform carbon tax as proposed by Weitzman (2014). The estimation assumes a demand elasticity of −0.8 and that gasoline pump prices are representative of energy prices. BAU emissions from 2009 to 2050 are assumed to stabilize at a certain level. Except for China, United States, India, Russian Federation, South Africa, Mexico and Brazil the emission forecasts from IEA are used. The budget range arises because emission levels and gasoline pump prices from 2008 and 2010 are employed in two scenarios.
** Egalitarian: Every person receives the same share of the global budget. Population numbers are from 2008 and different responsibility starting dates are plotted; × − responsibility starts in 2008. ● − responsibility starts in 1990.
*** Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013). The range arises from using different discount factors different (theta 0 and 1) for realized emission between 1990 and 2008.

Figure 16: Budget ranges derived from uniform tax, egalitarian approach, and equity principles



Global carbon budget until 2050 (Meinshausen et al., 2009) is allocated based on 3 approaches:
* Price: Implicit budget range from a uniform carbon tax as proposed by Weitzman (2014). The estimation assumes a demand elasticity of −0.8 and that gasoline pump prices are representative of energy prices. BAU emissions from 2009 to 2050 are assumed to stabilize at a certain level. Except for China, United States, India, Russian Federation, South Africa, Mexico and Brazil the emission forecasts from IEA are used. The budget range arises because emission levels and gasoline pump prices from 2008 and 2010 are employed in two scenarios.
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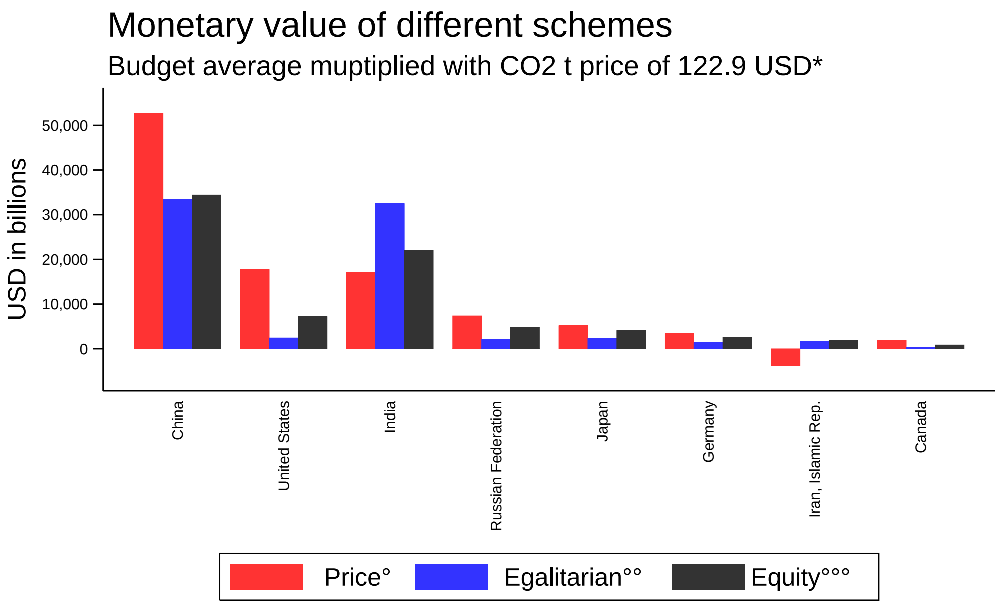
Figure 17: Budget ranges derived from uniform tax, egalitarian approach, and equity principles



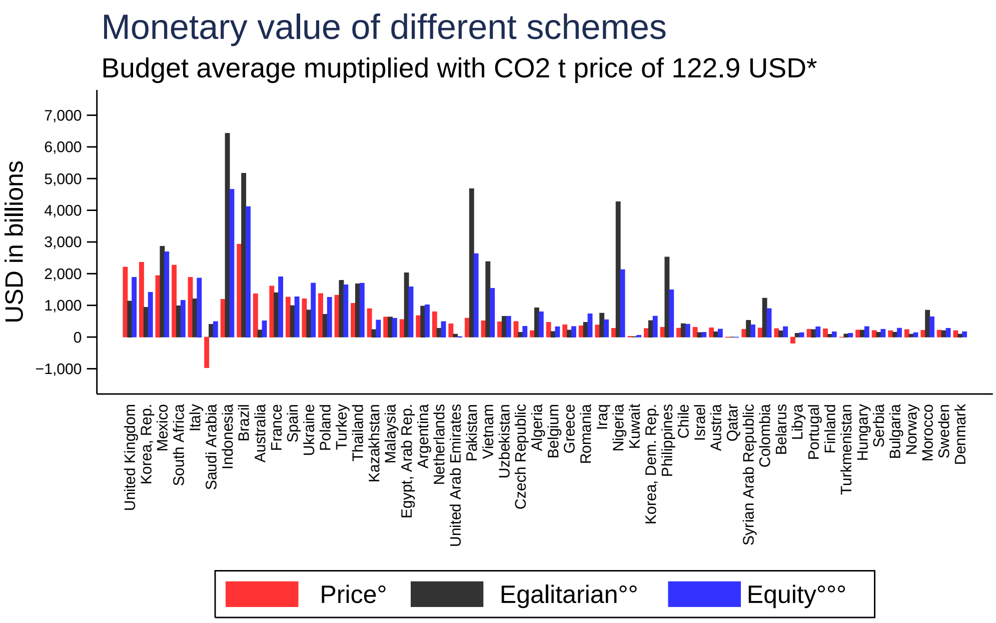
* The average of the previously calculated carbon budget allocations until 2050 for each of the three schemes is multiplied with the average value of a ton CO_2 when the demand elasticity is −0.8. CO_2 t price = (116.5+129.4)/2 = 122.9.

° Price: Approximated implicit budget resulting from a uniform carbon tax as proposed by Weitzman (2014).

°° Egalitarian: Every person receives the same share of the global budget until 2050.

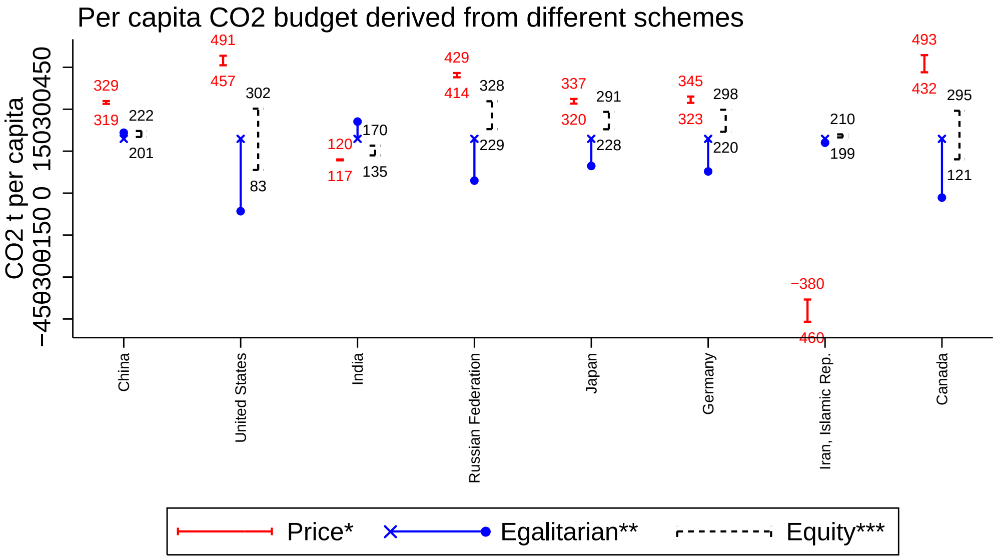
°°° Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013).

Figure 18: Monetary value of carbon budgets under different regimes



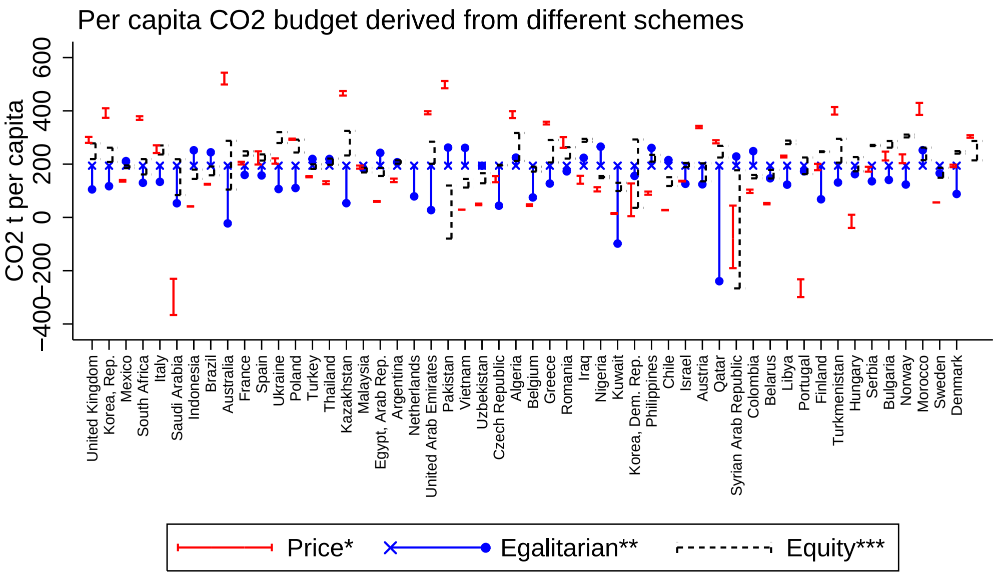
* The average of the previously calculated carbon budget allocations until 2050 for each of the three schemes is multiplied with the average value of a ton CO2 when the demand elasticity is −0.8. CO2 t price = (116.5+129.4)/2 = 122.9. Venezuela is excluded.
° Price: Approximated implicit budget resulting from a uniform carbon tax as proposed by Weitzman (2014).
°° Egalitarian: Every person receives the same share of the global budget until 2050.
°°° Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013).

Figure 19: Monetary value of carbon budgets under different regimes



Global carbon budget until 2050 (Meinshausen et al., 2009) is allocated based on 3 approaches:
* Price: Implicit budget range from a uniform carbon tax as proposed by Weitzman (2014). The estimation assumes a demand elasticity of −0.8 and that gasoline pump prices are representative of energy prices. BAU emissions from 2009 to 2050 are assumed to stabilize at a certain level. Except for China, United States, India, Russian Federation, South Africa, Mexico and Brazil the emission forecasts from IEA are used. The budget range arises because emission levels and gasoline pump prices from 2008 and 2010 are employed in two scenarios.
** Egalitarian: Every person receives the same share of the global budget. Population numbers are from 2008 and different responsibility starting dates are plotted; × − responsibility starts in 2008. • − responsibility starts in 1990.
*** Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013). The range arises from using different discount factors different (theta 0 and 1) for realized emission between 1990 and 2008.

Figure 20: Per capita budget ranges derived from uniform tax, egalitarian approach, and equity principles



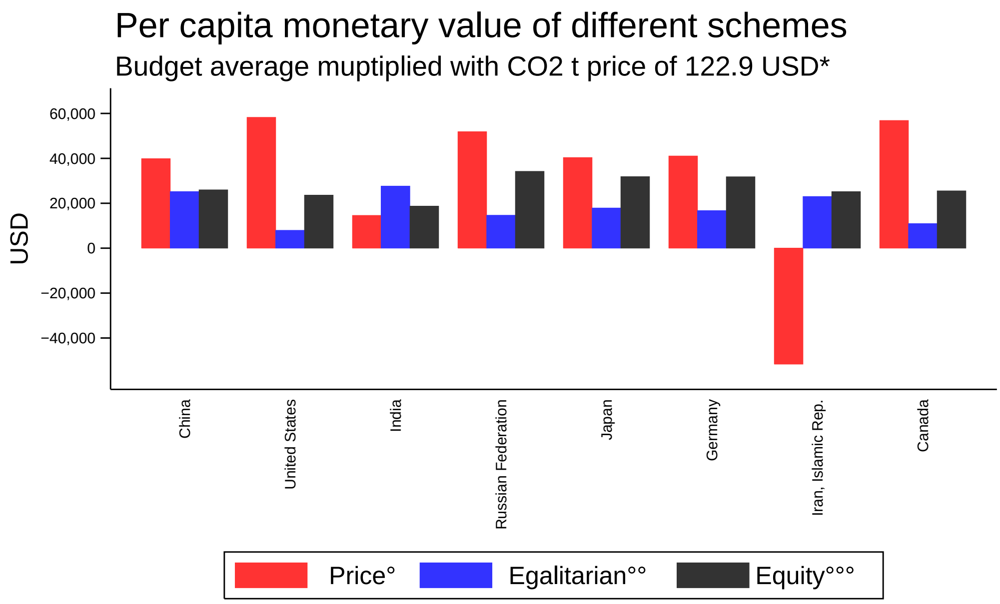
Global carbon budget until 2050 (Meinshausen et al., 2009) is allocated based on 3 approaches (Venezuela is excluded):

* Price: Implicit budget range from a uniform carbon tax as proposed by Weitzman (2014). The estimation assumes a demand elasticity of −0.8 and that gasoline pump prices are representative of energy prices. BAU emissions from 2009 to 2050 are assumed to stabilize at a certain level. Except for China, United States, India, Russian Federation, South Africa, Mexico and Brazil the emission forecasts from IEA are used. The budget range arises because emission levels and gasoline pump prices from 2008 and 2010 are employed in two scenarios.

** Egalitarian: Every person receives the same share of the global budget. Population numbers are from 2008 and different responsibility starting dates are plotted; × − responsibility starts in 2008. ● − responsibility starts in 1990.

*** Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013). The range arises from using different discount factors different (theta 0 and 1) for realized emission between 1990 and 2008.

Figure 21: Per capita budget ranges derived from uniform tax, egalitarian approach, and equity principles



* The average of the previously calculated carbon budget allocations until 2050 for each of the three schemes is multiplied with the average value of a ton CO2 when the demand elasticity is −0.8. CO2 t price = (116.5+129.4)/2 = 122.9.
° Price: Approximated implicit budget resulting from a uniform carbon tax as proposed by Weitzman (2014).
°° Egalitarian: Every person receives the same share of the global budget until 2050.
°°° Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013).

Figure 22: Per capita monetary value of carbon budgets under different regimes

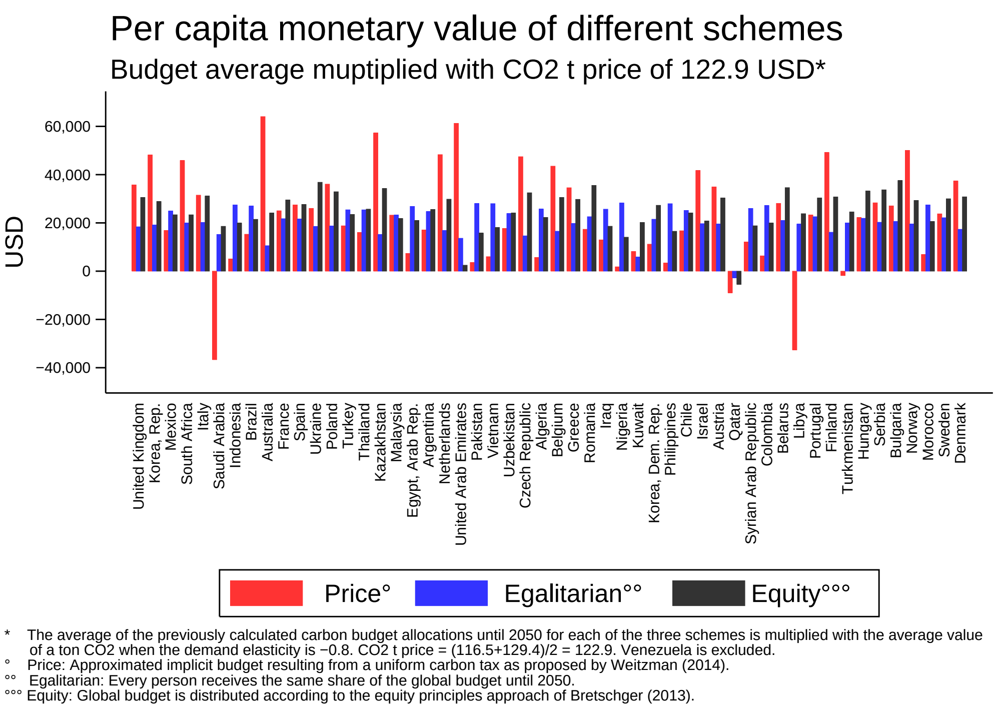


Figure 23: Per capita monetary value of carbon budgets under different regimes

4.6 US and China pledges in perspective

The presidents of China and the US recently announced their long term CO_2 abatement targets. Xi Jinping stated that China's CO_2 emissions peak in 2030 and that the share of non-fossil fuels in primary energy should be 20% by then. Barack Obama announced that the US intends to reduce its CO_2 emissions by 26 to 28% below its 2005 level in 2025.[5]

Figures 24 and 25 put this pledges into perspective. Figure 24 shows that Chinese emissions raised rapidly in the 21st century, growing annually on average 10%. The graph also shows predicted emissions according to different temperature targets for the period 2011 to 2050 from IEA (2014). The Chinese pledge of peak emissions is very vague because it is only a statement about the trend leaving too many degrees of freedom regarding the level. Based on this pledge we assume that starting in 2011 the emission growth declines at a linear rate until 2030 to 0 percent. This trend is then extrapolated until 2050. The dashed orange line in Figure 24 assumes emission growth of 7.5 percent in 2011 while the dashed khaki colored line starts with 5 percent emission growth. The average emission growth over the last five years was 7.5 percent. Under this trend emissions would peak at 17.8 Gt in 2030. But we think, that starting with emission growth of 5 percent is reasonable, since China faces increasingly pollution problems. With this growth trend emissions peak at 13.9 Gt in 2030. As can be seen in Figure 24, this emission level is slightly bellow IEA's BAU emissions for China.

In 2008 US emissions were at 5.8 Gt. Figure 25 shows along the past and predicted US emissions on the horizontal line the targeted emission level of 4.2 Gt in 2025 (72 percent of the 2000 level). We assume, that from 2011 onward US emissions decline linearly to the pledged level in 2025 and we extrapolate this declining trend until 2050. This is shown by the dashed khaki colored line in Figure 25.

Based on the hypothesized US and Chinese emission paths we calculate the cumulative emissions from 2009 to 2050 for theses two countries. These budgets are compared in Figure 26 to our calculated budget allocations under a price scheme using IEA's emission predictions as in Section 4.5 as well as under egalitarian and equity schemes. The horizontal gray line in Figure 26 shows to what budgets the pledges amount under our emission trend assumptions. China demands a emission budget of 491 Gt CO_2 from 2008 to 2050 and the US calls for 161 Gt. Since the remaining budget until 2050 under a 2 degree warming target is 1066 Gt, China demands 46 percent of the emission pie and the US 15 percent. These two countries currently emit together 40 percent of worldwide emissions and claim 61 percent of the remaining emission budget until 2050.

We established earlier that the US and China get the highest emission al-

[5] `http://www.whitehouse.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change`, visited on November 13 2014

locations under a price scheme. Figure 26 illustrates that these two countries get a much higher budget under a price scheme as opposed to an egalitarian or an equity scheme. But according to our calculations, the emission pledges of these two key emitters overshoot even their budget under a price scheme. Notably, this overshooting is more pronounced for China than for the US. China and the US implicitly ask the rest of the world to additionally compensate their weak emission targets.

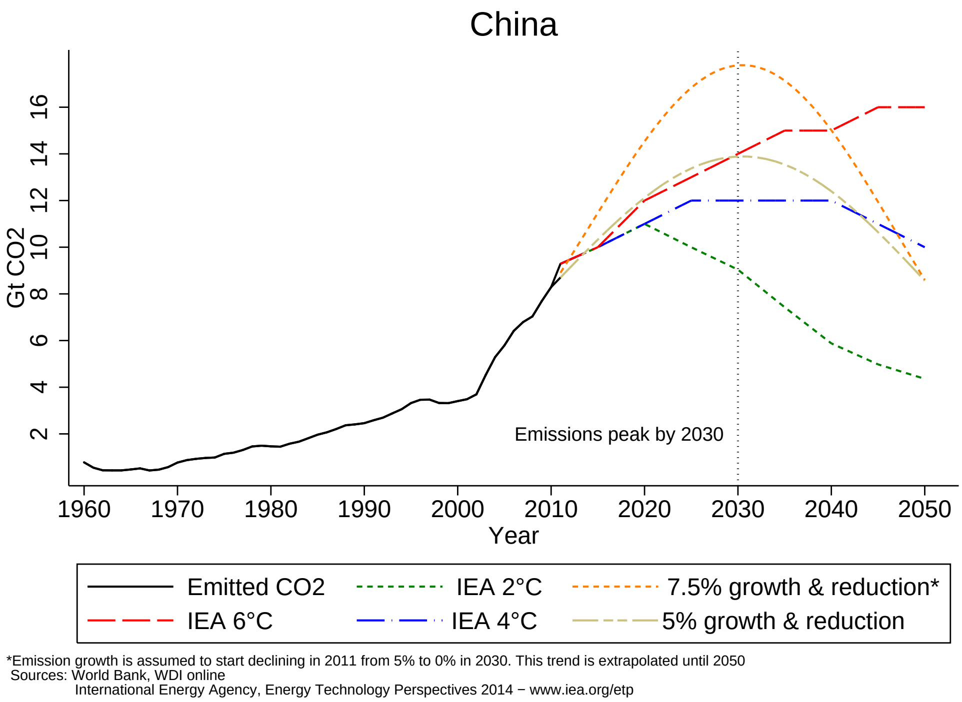


Figure 24: Historic, predicted and pledged Chinese emissions

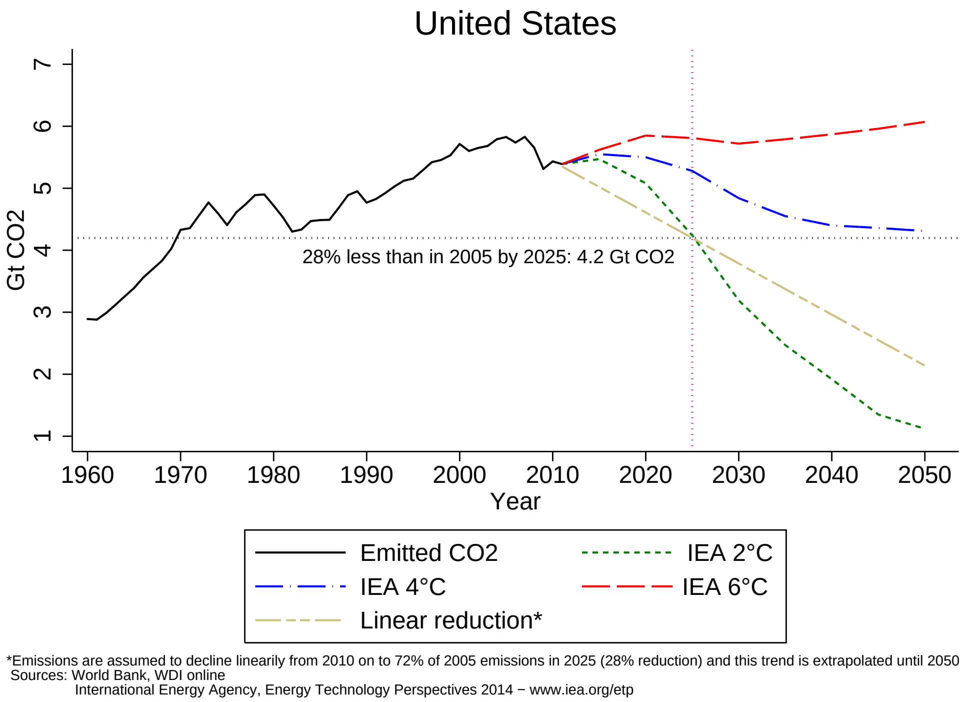
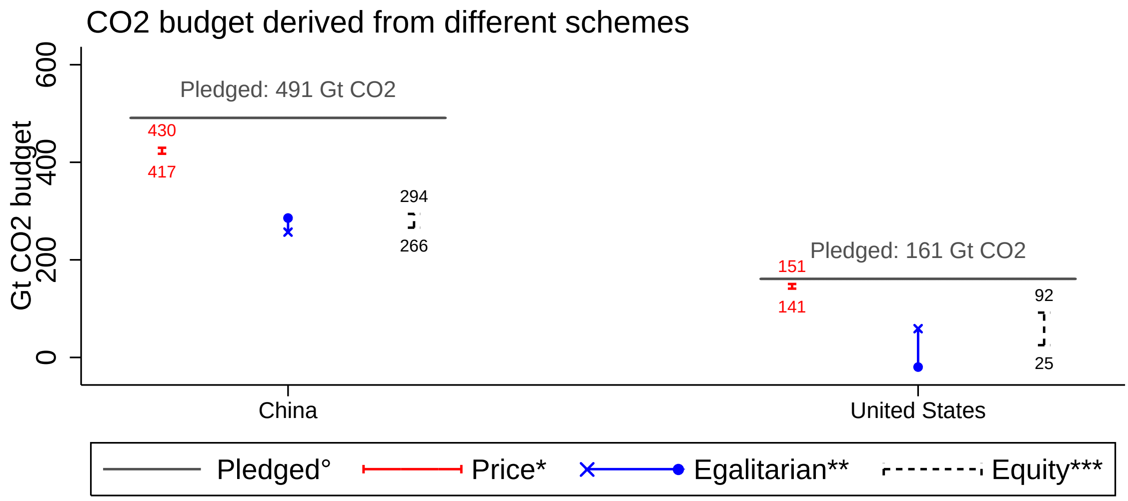


Figure 25: Historic, predicted and pledged US emissions



° China: We assumed that starting in 2011, its emission grwoth rate linearly declines from a 5% level to 0 in 2030 and extrapolate.
US: We assumed that starting in 2011, its emission linearly decline to 72% of its 2005 emissions in 2003 and extrapolate.

Global carbon budget until 2050 (Meinshausen et al., 2009) is allocated based on 3 approaches:
* Price: Implicit budget range from a uniform carbon tax as proposed by Weitzman (2014). The estimation assumes a demand elasticity of −0.8 and that gasoline pump prices are representative of energy prices. BAU emissions from 2009 to 2050 are assumed to stabilize at a certain level. Except for China, United States, India, Russian Federation, South Africa, Mexico and Brazil the emission forecasts from IEA are used. The budget range arises because emission levels and gasoline pump prices from 2008 and 2010 are employed in two scenarios.
** Egalitarian: Every person receives the same share of the global budget. Population numbers are from 2008 and different responsibility starting dates are plotted; × − responsibility starts in 2008. ● − responsibility starts in 1990.
*** Equity: Global budget is distributed according to the equity principles approach of Bretschger (2013). The range arises from using different discount factors different (theta 0 and 1) for realized emission between 1990 and 2008.

Figure 26: Comparison of budgets for US and China

5 Conclusion

The paper demonstrates that international climate policy has major distributional consequences. We have compared the emission budget allocation across major emitter countries under three recently proposed policy design mechanisms. Whereas Weitzman (2014) stresses the advantages of negotiating a globally uniform quantity tax on carbon, Bretschger (2013) derives country shares of the global emission budget based on major equity principles, reflecting equal access to sustainable development. We calculate the implicit CO_2 budget distribution of a uniform tax and compare it with the budget allocation proposed by Bretschger (2013) and with the budget division under egalitarian rights to emit carbon dioxide, reflecting equal access to carbon space.

Our comparison illustrates the distributional impacts of climate policies. As soon as carbon has a positive price, carbon budgets directly translate into monetary terms. Based on our findings, it is not surprising which countries favor which policy designs. Policies maximizing the own budget are naturally preferred. But the analysis also shows that the burden sharing is robust for a number of countries, irrespective of the chosen policy design. Additionally, our analysis also illustrates that the recent emission pledges of China and the US result in an overshooting of the budgets obtained under any of the three analyzed climate policy schemes. Every low emission pledge implicitly asks the rest of the world to compensate for the weakness of the pledge.

Carbon budget comparisons could be extended to other recently suggested equity regimes. Then, an even more complete robustness check for burden sharing under different regimes could be done. Together with the results of the present paper this will help to evaluate the country pledges, which are requested for the preparation of the important climate negotiations at the COP 21 in Paris.

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Appendix

A Tables

Table A1: Country rank & share of worldwide CO_2 emissions in 2008

Country	Rank	CO_2 Gt	$\%CO_2$ of world	$\sum\%CO_2$ of world	t CO_2 PC	Pop in mio	GDP PC	CO_2 intensity
China	1	7.04	21.84	21.84	5.31	1324.66	3.41	1.56
United States	2	5.66	17.56	39.41	18.60	304.09	48.41	0.38
India	3	1.81	5.62	45.03	1.54	1174.66	1.04	1.48
Russian Federation	4	1.72	5.33	50.36	12.09	141.95	11.70	1.03
Japan	5	1.21	3.75	54.11	9.45	127.70	37.97	0.25
Germany	6	0.78	2.43	56.54	9.54	82.11	44.13	0.22
Iran, Islamic Rep.	7	0.57	1.77	58.31	7.85	72.66	4.90	1.60
Canada	8	0.54	1.69	60.00	16.39	33.25	45.20	0.36
United Kingdom	9	0.52	1.62	61.62	8.46	61.77	43.51	0.19
Korea, Rep.	10	0.51	1.58	63.20	10.38	48.95	19.03	0.55
Mexico	11	0.47	1.46	64.67	4.10	114.97	9.56	0.43
South Africa	12	0.47	1.44	66.11	9.38	49.56	5.51	1.70
Italy	13	0.45	1.39	67.50	7.47	59.83	38.56	0.19
Saudi Arabia	14	0.42	1.30	68.80	15.86	26.37	19.71	0.80
Indonesia	15	0.41	1.28	70.08	1.76	234.24	2.18	0.81
Brazil	16	0.39	1.20	71.28	2.02	191.77	8.62	0.23
Australia	17	0.39	1.20	72.48	18.24	21.25	49.67	0.37
France	18	0.37	1.16	73.64	5.79	64.37	43.99	0.13
Spain	19	0.33	1.02	74.66	7.17	45.95	34.67	0.21
Ukraine	20	0.32	1.00	75.67	6.99	46.26	3.89	1.80
Poland	21	0.32	0.98	76.65	8.29	38.13	13.89	0.60
Turkey	22	0.29	0.89	77.53	4.05	70.36	10.38	0.39
Thailand	23	0.26	0.81	78.35	3.96	66.19	4.12	0.96
Kazakhstan	24	0.23	0.72	79.06	14.70	15.67	8.51	1.73
Malaysia	25	0.21	0.66	79.73	7.81	27.30	8.46	0.92
Egypt, Arab Rep.	26	0.20	0.61	80.34	2.61	75.49	2.16	1.21
Argentina	27	0.19	0.59	80.93	4.79	39.68	8.23	0.58
Venezuela, RB	28	0.19	0.58	81.51	6.64	28.12	11.22	0.59
Netherlands	29	0.17	0.54	82.05	10.57	16.45	52.95	0.20
United Arab Emirates	30	0.16	0.49	82.54	23.38	6.80	46.40	0.50
Pakistan	31	0.16	0.49	83.03	0.94	167.01	1.02	0.92
Vietnam	32	0.13	0.39	83.42	1.49	85.12	1.16	1.28
Uzbekistan	33	0.12	0.37	83.79	4.40	27.30	1.02	4.30
Czech Republic	34	0.12	0.36	84.16	11.27	10.38	21.71	0.52
Algeria	35	0.11	0.36	84.51	3.21	35.73	4.79	0.67
Belgium	36	0.10	0.32	84.84	9.70	10.71	47.37	0.20
Greece	37	0.10	0.30	85.14	8.70	11.24	30.40	0.29
Romania	38	0.09	0.29	85.43	4.61	20.54	9.95	0.46
Iraq	39	0.09	0.29	85.73	3.21	29.43	4.47	0.72
Nigeria	40	0.09	0.29	86.01	0.61	151.21	1.38	0.45
Kuwait	41	0.08	0.25	86.26	29.59	2.70	54.55	0.54
Korea, Dem. Rep.	42	0.08	0.24	86.50	3.22	24.24		
Philippines	43	0.08	0.24	86.74	0.84	90.37	1.92	0.44
Chile	44	0.07	0.22	86.96	4.23	16.83	10.67	0.40
Israel	45	0.07	0.22	87.18	9.71	7.31	29.16	0.33
Austria	46	0.07	0.21	87.39	8.19	8.34	49.68	0.16
Qatar	47	0.07	0.21	87.60	50.03	1.36	84.81	0.59
Syrian Arab Republic	48	0.07	0.21	87.82	3.33	20.35		
Colombia	49	0.07	0.21	88.02	1.47	45.15	5.41	0.27
Belarus	50	0.06	0.20	88.22	6.59	9.53	6.38	1.03
Libya	51	0.06	0.19	88.40	10.28	5.88	15.85	0.65
Portugal	52	0.06	0.18	88.59	5.53	10.56	23.86	0.23
Finland	53	0.06	0.18	88.76	10.65	5.31	51.19	0.21
Turkmenistan	54	0.06	0.17	88.93	11.20	4.92	3.92	2.86
Hungary	55	0.05	0.17	89.10	5.44	10.04	15.36	0.35
Serbia	56	0.05	0.16	89.26	7.06	7.35	6.50	1.09
Bulgaria	57	0.05	0.16	89.42	6.78	7.49	6.92	0.98
Norway	58	0.05	0.16	89.58	10.55	4.77	95.19	0.11
Morocco	59	0.05	0.16	89.73	1.61	30.96	2.87	0.56
Sweden	60	0.05	0.15	89.88	5.33	9.22	52.73	0.10
Denmark	61	0.05	0.15	90.03	8.55	5.49	62.60	0.14

Rank: Country rank in CO_2 emissions, CO_2 Gt: CO_2 Gt emissions, $\%CO_2$ of WLD: % Share of worldwide CO_2 emissions, $\sum\%CO_2$ of WLD: % CO_2 of worldwide CO_2 cumulative, CO_2 PC: CO_2 tons per capita, Pop in mio: Total population in millions, GDP PC: GDP in USD per capita, CO_2 intensity: CO_2 emissions in tons per 1000 USD of GDP

Table A2: Countries 2008 rank according to CO_2 per capita (PC) emissions

Country	Rank	t CO_2 PC	$\%CO_2$ of world	$\sum\%CO_2$ of world	PC Oil-eq prod.	Fossil rents % GDP	$P_{gasoline}$
Qatar	1	50.03	0.21	0.21	98.93	47.34	0.22
Trinidad and Tobago	2	32.31	0.13	0.34	32.12	61.78	0.36
Kuwait	3	29.59	0.25	0.59	56.69	63.71	0.24
Brunei Darussalam	4	27.27	0.03	0.62	54.45	71.75	0.38
United Arab Emirates	5	23.38	0.49	1.12	27.51	30.57	0.45
Aruba	6	22.58	0.01	1.12			
Luxembourg	7	22.09	0.03	1.16	0.26	0.00	1.40
Bahrain	8	21.77	0.08	1.23	15.67	34.98	0.21
United States	9	18.60	17.56	18.80	5.60	2.19	0.56
Australia	10	18.24	1.20	20.00	13.30	4.79	0.74
Canada	11	16.39	1.69	21.69	12.19	6.86	0.76
Saudi Arabia	12	15.86	1.30	22.99	21.97	64.05	0.16
Oman	13	15.83	0.13	23.12	24.46	54.71	0.31
Kazakhstan	14	14.70	0.72	23.83	9.21	45.80	0.83
Faeroe Islands	15	14.49	0.00	23.84			
New Caledonia	16	13.45	0.01	23.85			
Estonia	17	13.05	0.05	23.90	3.15	0.70	1.18
Russian Federation	18	12.09	5.33	29.23	8.83	29.75	0.89
Cayman Islands	19	11.92	0.00	29.23			
Greenland	20	11.33	0.00	29.23			
Czech Republic	21	11.27	0.36	29.60	3.16	0.72	1.37
Turkmenistan	22	11.20	0.17	29.77	13.85		0.22
Finland	23	10.65	0.18	29.94	3.10	0.00	1.57
Netherlands	24	10.57	0.54	30.48	4.05	2.76	1.68
Norway	25	10.55	0.16	30.64	45.93	21.79	1.63
Korea, Rep.	26	10.38	1.58	32.22	0.91	0.03	1.51
Palau	27	10.33	0.00	32.22			
Libya	28	10.28	0.19	32.40	18.22	63.94	0.14
Israel	29	9.71	0.22	32.62	0.53	0.54	1.37
Belgium	30	9.70	0.32	32.95	1.36	0.00	1.50
Ireland	31	9.58	0.13	33.08	0.35	0.05	1.56
Germany	32	9.54	2.43	35.51	1.66	0.26	1.56
Japan	33	9.45	3.75	39.26	0.69	0.03	1.42
South Africa	34	9.38	1.44	40.70	3.26	7.60	0.87
Greece	35	8.70	0.30	41.01	0.88	0.08	1.23
Denmark	36	8.55	0.15	41.15	4.85	3.51	1.54
Slovenia	37	8.50	0.05	41.21	1.82	0.13	1.18
United Kingdom	38	8.46	1.62	42.83	2.70	2.44	1.44
Poland	39	8.29	0.98	43.81	1.87	1.61	1.43
Austria	40	8.19	0.21	44.02	1.35	0.25	1.37
Seychelles	41	8.14	0.00	44.02			
Bosnia and Herzegovina	42	8.03	0.10	44.12	1.10	2.59	1.13
New Zealand	43	8.03	0.11	44.23	3.51	2.60	1.09
Cyprus	44	7.94	0.03	44.25	0.08	0.00	1.28
Iran, Islamic Rep.	45	7.85	1.77	46.03	4.64	50.67	0.10
Malaysia	46	7.81	0.66	46.69	3.37	18.38	0.53
Italy	47	7.47	1.39	48.08	0.45	0.27	1.57
Spain	48	7.17	1.02	49.10	0.66	0.03	1.23
Serbia	49	7.06	0.16	49.26	1.46	1.85	1.29
Ukraine	50	6.99	1.00	50.26	1.82	7.43	0.88
Slovak Republic	51	6.98	0.12	50.38	1.19	0.06	1.57
Equatorial Guinea	52	6.84	0.01	50.39			
Bulgaria	53	6.78	0.16	50.55	1.37	0.40	1.28
Andorra	54	6.74	0.00	50.55			1.24
Iceland	55	6.68	0.01	50.56	13.72	0.00	1.15
Venezuela, RB	56	6.64	0.58	51.14	7.29	33.95	0.02
Belarus	57	6.59	0.20	51.34	0.42	1.87	1.33
Malta	58	6.25	0.01	51.34	0.00	0.00	1.66
Bermuda	59	5.96	0.00	51.34			
Barbados	60	5.89	0.01	51.35			1.00
France	61	5.79	1.16	52.51	2.12	0.03	1.52

Rank: Rank in CO_2 tons per capita, CO_2 PC: CO_2 tons per capita, $\%CO_2$ of world: % Share at worldwide CO_2 emissions, $\sum\%CO_2$ of world: $\%CO_2$ of worldwide CO_2 cummulated, PC Oil-eq prod.: Per capita oil equivalent energy production in tons, Energy production in Mt Oil equivalents, Fossil rents % GDP: Sum of coal, oil and natural gas rents rents in % of GDP, $P_{gasoline}$: Gasoline pump price in USD

Table A3: Uniform price, 2 °C warming with 50% prob.*, 2008 base

Variable	**Value**	**Definition**
E_B	1440	Emission budget 2000-2050*
ER	256	Realized emissions 2000-2008
RE_B	1066	Remaining emission budget 2009-2050
EA	29	Emission average if year==2008
TEF	1189	Total emission forecast 2009-2050
EE	123	Excess emissions to attain warming target
$PA_{gasoline}$	1.00	Average price for gasoline in USD
τ	0.07	Energy (gasoline) quantity tax
CF	432.63	# Liter gasoline for 1 t CO_2
ϵ	-0.80	Long run demand elasticity of gasoline
P_{tCO_2}	31.64	Price for 1 t CO_2

*According to Meinshausen et al. (2009), 1440 GT CO_2 can be emitted until 2050. Our sample covers 90% of the worldwide emissions in 2008.

Table A4: Uniform price, 2 °C warming with 50% prob.*, 2010 base

Variable	**Value**	**Definition**
E_B	1440	Emission budget 2000-2050*
ER	256	Realized emissions 2000-2008
RE_B	1066	Remaining emission budget 2009-2050
EA	30	Emission average if year==2010
TEF	1238	Total emission forecast 2009-2050
EE	172	Excess emissions to attain warming target
$PA_{gasoline}$	1.20	Average price for gasoline in USD
τ	0.11	Energy (gasoline) quantity tax
CF	432.63	# Liter gasoline for 1 t CO_2
ϵ	-0.80	Long run demand elasticity of gasoline
P_{tCO_2}	48.31	Price for 1 t CO_2

*According to Meinshausen et al. (2009), 1440 GT CO_2 can be emitted until 2050. Our sample covers 90% of the worldwide emissions in 2010.

Table A5: Uniform price with base year 2010, +2 °C with 50% probability

Country	Rank	$P_{gasoline}$	% rise $P_{gasoline}$	% reduction D	Gt CO_2 reduction	Gt CO_2 budget
China	1	0.99	11.28	−9.02	−30.66	309.10
United States	2	0.56	19.94	−15.95	−35.53	187.22
India	3	1.09	10.24	−8.20	−6.75	75.61
Russian Federation	4	0.89	12.55	−10.04	−7.16	64.21
Japan	5	1.42	7.86	−6.29	−3.02	44.98
Germany	6	1.56	7.16	−5.73	−1.75	28.81
Iran, Islamic Rep.	7	0.10	111.66	−89.33	−20.94	2.50
Canada	8	0.76	14.69	−11.75	−2.41	18.06
United Kingdom	9	1.44	7.75	−6.20	−1.26	18.98
Korea, Rep.	10	1.51	7.40	−5.92	−1.38	21.89
Mexico	11	0.74	15.09	−12.07	−2.20	15.99
South Africa	12	0.87	12.84	−10.27	−1.94	16.93
Italy	13	1.57	7.11	−5.69	−0.95	15.71
Saudi Arabia	14	0.16	69.79	−55.83	−10.63	8.41
Indonesia	15	0.50	22.33	−17.87	−3.18	14.61
Brazil	16	1.26	8.86	−7.09	−1.22	15.99
Australia	17	0.74	15.09	−12.07	−1.85	13.45
France	18	1.52	7.35	−5.88	−0.87	13.94
Spain	19	1.23	9.08	−7.26	−0.80	10.25
Ukraine	20	0.88	12.69	−10.15	−1.27	11.23
Poland	21	1.43	7.81	−6.25	−0.81	12.19
Turkey	22	1.87	5.97	−4.78	−0.58	11.63
Thailand	23	0.87	12.84	−10.27	−1.24	10.86
Kazakhstan	24	0.83	13.45	−10.76	−1.10	9.10
Malaysia	25	0.53	21.07	−16.86	−1.50	7.39
Egypt, Arab Rep.	26	0.49	22.79	−18.23	−1.53	6.87
Argentina	27	0.78	14.32	−11.45	−0.85	6.55
Venezuela, RB	28	0.02	558.32	−446.66	−36.95	−28.67
Netherlands	29	1.68	6.65	−5.32	−0.40	7.07
United Arab Emirates	30	0.45	24.81	−19.85	−1.36	5.51
Pakistan	31	0.84	13.29	−10.63	−0.70	5.91
Vietnam	32	0.80	13.96	−11.17	−0.69	5.47
Uzbekistan	33	1.35	8.27	−6.62	−0.28	4.00
Czech Republic	34	1.37	8.15	−6.52	−0.30	4.28
Algeria	35	0.34	32.84	−26.27	−1.33	3.73
Belgium	36	1.50	7.44	−5.96	−0.27	4.20
Greece	37	1.23	9.08	−7.26	−0.26	3.30
Romania	38	1.11	10.06	−8.05	−0.26	2.97
Iraq	39	0.78	14.32	−11.45	−0.54	4.16
Nigeria	40	0.59	18.93	−15.14	−0.49	2.75
Kuwait	41	0.24	46.53	−37.22	−1.43	2.41
Korea, Dem. Rep.	42	0.76	14.69	−11.75	−0.35	2.59
Philippines	43	0.91	12.27	−9.82	−0.33	3.02
Chile	44	0.95	11.75	−9.40	−0.28	2.68
Israel	45	1.37	8.15	−6.52	−0.19	2.71
Austria	46	1.37	8.15	−6.52	−0.18	2.56
Qatar	47	0.22	50.76	−40.61	−1.17	1.72
Syrian Arab Republic	48	0.85	13.14	−10.51	−0.27	2.27
Colombia	49	1.04	10.74	−8.59	−0.27	2.84
Belarus	50	1.33	8.40	−6.72	−0.17	2.38
Libya	51	0.14	79.76	−63.81	−1.54	0.88
Portugal	52	1.61	6.94	−5.55	−0.12	2.03
Finland	53	1.57	7.11	−5.69	−0.14	2.39
Turkmenistan	54	0.22	50.76	−40.61	−0.88	1.29
Hungary	55	1.27	8.79	−7.03	−0.15	1.93
Serbia	56	1.29	8.66	−6.92	−0.13	1.75
Bulgaria	57	1.28	8.72	−6.98	−0.13	1.70
Norway	58	1.63	6.85	−5.48	−0.13	2.22
Morocco	59	1.29	8.66	−6.92	−0.14	1.93
Sweden	60	1.38	8.09	−6.47	−0.14	2.01
Denmark	61	1.54	7.25	−5.80	−0.11	1.79

Rank: Country rank in CO2 emissions, $P_{gasoline}$: p/l gasoline in USD, % $P_{gasoline}$ rise: % p/l rise due to tax, % reduction D: Induced demand reduction, Gt CO_2 reduction: Gt CO_2 reduction due to tax, CO_2 budget: New CO_2 budget in Gt

Table A6: CO_2 budgets comparison until 2050 (1440 CO_2 t)

		Unifomrm CO_2 price		Egalitarian approach		Equity principles	
Country	rank	2008 base year	2010 base year	1990 responsibility	2008 responsibility	$\theta = 0$	$\theta = 1$
China	1	274.4	312.0	257.3	286.2	266.0	294.2
United States	2	207.6	186.4	59.1	-19.6	91.9	25.2
India	3	71.1	76.4	228.2	300.4	158.5	199.5
Russian Federation	4	66.3	64.7	27.6	6.3	46.6	32.5
Japan	5	48.2	45.6	24.8	12.4	37.1	29.2
Germany	6	31.4	29.2	15.9	6.4	24.5	18.0
Iran, Islamic Rep.	7	7.0	-0.6	14.1	13.1	15.3	14.5
Canada	8	20.8	18.1	6.5	-0.5	9.8	4.0
United Kingdom	9	20.9	19.3	12.0	6.5	17.2	13.5
Korea, Rep.	10	20.3	22.2	9.5	5.7	12.8	10.2
Mexico	11	17.9	16.1	22.3	24.3	21.3	22.5
South Africa	12	17.9	17.0	9.6	6.4	10.8	8.0
Italy	13	17.9	16.0	11.6	8.0	16.2	14.1
Saudi Arabia	14	9.8	7.0	5.1	1.4	5.8	2.2
Indonesia	15	14.9	14.5	45.5	59.1	33.8	42.0
Brazil	16	15.4	16.2	37.2	46.9	30.4	36.7
Australia	17	14.7	13.5	4.1	-0.5	6.1	2.2
France	18	14.9	14.1	12.5	10.3	16.0	14.9
Spain	19	13.0	10.4	8.9	7.2	10.9	9.8
Ukraine	20	12.5	11.3	9.0	4.9	14.8	12.9
Poland	21	12.6	12.4	7.4	4.2	11.1	9.3
Turkey	22	11.5	11.8	13.7	15.4	12.8	14.0
Thailand	23	10.1	10.9	12.9	14.5	13.1	14.6
Kazakhstan	24	8.9	9.2	3.0	0.8	5.1	3.6
Malaysia	25	7.8	7.3	5.3	5.0	5.1	4.6
Egypt, Arab Rep.	26	7.1	6.8	14.7	18.3	11.7	14.0
Argentina	27	7.3	6.6	7.7	8.2	8.0	8.5
Venezuela, RB	28	-19.8	-35.0	5.5	4.8	5.6	4.9
Netherlands	29	7.0	7.2	3.2	1.3	4.7	3.3
United Arab Emirates	30	5.6	5.4	1.3	0.2	0.8	-0.5
Pakistan	31	6.0	6.0	32.4	43.8	18.7	24.1
Vietnam	32	4.9	5.5	16.5	22.2	10.9	14.1
Uzbekistan	33	4.8	4.1	5.3	5.3	5.4	5.3
Czech Republic	34	4.7	4.3	2.0	0.5	3.3	2.2
Algeria	35	3.8	3.6	6.9	8.0	6.1	6.8
Belgium	36	4.2	4.3	2.1	0.8	3.1	2.2
Greece	37	3.9	3.3	2.2	1.4	3.0	2.5
Romania	38	3.7	3.0	4.0	3.6	5.8	6.1
Iraq	39	3.6	4.2	5.7	6.6	4.3	4.6
Nigeria	40	3.4	2.7	29.4	40.2	15.0	19.6
Kuwait	41	2.4	2.3	0.5	-0.3	0.8	0.1
Korea, Dem. Rep.	42	3.0	2.6	4.7	3.8	5.7	5.1
Philippines	43	2.9	3.0	17.6	23.6	10.7	13.6
Chile	44	2.8	2.7	3.3	3.6	3.2	3.4
Israel	45	2.8	2.7	1.4	0.9	1.5	1.0
Austria	46	2.7	2.6	1.6	1.0	2.2	1.9
Qatar	47	1.9	1.6	0.3	-0.3	0.2	-0.4
Syrian Arab Republic	48	2.6	2.3	4.0	4.7	3.0	3.2
Colombia	49	2.6	2.9	8.8	11.2	6.6	8.0
Belarus	50	2.5	2.4	1.9	1.4	2.7	2.6
Libya	51	1.3	0.7	1.1	0.7	1.3	1.0
Portugal	52	2.3	2.1	2.1	1.8	2.6	2.6
Finland	53	2.3	2.4	1.0	0.4	1.6	1.1
Turkmenistan	54	1.6	1.2	1.0	0.6	1.1	0.9
Hungary	55	2.2	2.0	1.9	1.6	2.7	2.7
Serbia	56	2.1	1.8	1.4	1.0	2.1	1.9
Bulgaria	57	2.0	1.7	1.5	1.1	2.3	2.3
Norway	58	2.0	2.3	0.9	0.6	1.2	1.0
Morocco	59	2.0	2.0	6.0	7.8	4.6	5.8
Sweden	60	2.0	2.0	1.8	1.5	2.3	2.2
Denmark	61	1.9	1.8	1.1	0.5	1.6	1.2

Rank: Country rank in CO2 emissions, Uniform price - 2008/2010 base: Implied CO_2 budget from an uniform carbon price bassed on 2008/2010 emissions and prices, Egalitarian - 1990/2008: Egalitiarian per capita approach with responsibility starting in 1990 and 2008 respectively, $\theta = 0$ & $\theta = 1$: CO_2 budget according to Bretschger (2013) with discount rate θ

B Emission Forecasts

Table B7: Uniform price, 2 °C warming with 50% prob.*, 2008 base

Variable	**Value**	**Definition**
E_B	1440	Emission budget 2000-2050*
ER	256	Realized emissions 2000-2008
RE_B	1066	Remaining emission budget 2009-2050
EA	38	Emission average if year==2008
TEF	1570	Total emission forecast 2009-2050
EE	504	Excess emissions to attain warming target
$PA_{gasoline}$	1.00	Average price for gasoline in USD
τ	0.25	Energy (gasoline) quantity tax
CF	432.63	# Liter gasoline for 1 t CO_2
ϵ	-0.80	Long run demand elasticity of gasoline
P_{tCO_2}	109.91	Price for 1 t CO_2

*According to Meinshausen et al. (2009), 1440 GT CO_2 can be emitted until 2050. Our sample covers 90% of the worldwide emissions in 2008.

Table B8: Uniform price, 2 °C warming with 50% prob.*, 2010 base

Variable	**Value**	**Definition**
E_B	1440	Emission budget 2000-2050*
ER	256	Realized emissions 2000-2008
RE_B	1066	Remaining emission budget 2009-2050
EA	38	Emission average if year==2010
TEF	1568	Total emission forecast 2009-2050
EE	502	Excess emissions to attain warming target
$PA_{gasoline}$	1.20	Average price for gasoline in USD
τ	0.28	Energy (gasoline) quantity tax
CF	432.63	# Liter gasoline for 1 t CO_2
ϵ	-0.80	Long run demand elasticity of gasoline
P_{tCO_2}	122.06	Price for 1 t CO_2

*According to Meinshausen et al. (2009), 1440 GT CO_2 can be emitted until 2050. Our sample covers 90% of the worldwide emissions in 2010.

Table B9: Prices for 2 °C warming with 50% prob.* and different elasticities

		gasoline price & emissions	
Elasticity	**Prices**	**2008 base**	**2010 base**
$\epsilon = -0.5$	τ : CO_2 tax	0.41	0.45
	P_{tCO_2} : Price per t	175.86	195.30
$\epsilon = -0.8$	τ : CO_2 tax	0.25	0.28
	P_{tCO_2} : Price per t CO_2	109.91	122.06
$\epsilon = -1$	τ : CO_2 tax	0.20	0.23
	P_{tCO_2} : Price per t CO_2	87.93	97.65

*According to Meinshausen et al. (2009), 1440 GT CO_2 can be emitted until 2050. Our sample covers 90% of the worldwide emissions in 2010.

Table B10: Uniform price with base year 2008, +2 °C with 50% probability

Country	Rank	$P_{gasoline}$	% rise $P_{gasoline}$	% reduction D	CO_2 reduction	CO_2 budget
China	1	0.99	25.66	−20.53	−111.11	430.10
United States	2	0.56	45.37	−36.29	−85.89	150.76
India	3	1.09	23.31	−18.65	−31.64	138.04
Russian Federation	4	0.89	28.55	−22.84	−17.92	60.55
Japan	5	1.42	17.89	−14.31	−7.08	42.40
Germany	6	1.56	16.29	−13.03	−4.18	27.93
Iran, Islamic Rep.	7	0.10	254.05	−203.24	−47.55	−24.15
Canada	8	0.76	33.43	−26.74	−5.98	16.37
United Kingdom	9	1.44	17.64	−14.11	−3.02	18.40
Korea, Rep.	10	1.51	16.82	−13.46	−2.80	18.03
Mexico	11	0.74	34.33	−27.47	−6.09	16.08
South Africa	12	0.87	29.20	−23.36	−5.67	18.61
Italy	13	1.57	16.18	−12.95	−2.37	15.96
Saudi Arabia	14	0.16	158.78	−127.03	−21.78	−4.63
Indonesia	15	0.50	50.81	−40.65	−6.87	10.04
Brazil	16	1.26	20.16	−16.13	−4.55	23.66
Australia	17	0.74	34.33	−27.47	−4.37	11.53
France	18	1.52	16.71	−13.37	−2.04	13.23
Spain	19	1.23	20.65	−16.52	−2.23	11.27
Ukraine	20	0.88	28.87	−23.10	−3.06	10.20
Poland	21	1.43	17.77	−14.21	−1.84	11.12
Turkey	22	1.87	13.59	−10.87	−1.27	10.43
Thailand	23	0.87	29.20	−23.36	−2.51	8.23
Kazakhstan	24	0.83	30.61	−24.49	−2.31	7.13
Malaysia	25	0.53	47.93	−38.35	−3.35	5.39
Egypt, Arab Rep.	26	0.49	51.85	−41.48	−3.35	4.72
Argentina	27	0.78	32.57	−26.06	−2.03	5.76
Venezuela, RB	28	0.02	1270.26	−1016.21	−77.83	−70.17
Netherlands	29	1.68	15.12	−12.10	−0.86	6.27
United Arab Emirates	30	0.45	56.46	−45.16	−2.94	3.57
Pakistan	31	0.84	30.24	−24.20	−1.55	4.87
Vietnam	32	0.80	31.76	−25.41	−1.32	3.89
Uzbekistan	33	1.35	18.82	−15.05	−0.74	4.18
Czech Republic	34	1.37	18.54	−14.84	−0.71	4.09
Algeria	35	0.34	74.72	−59.78	−2.81	1.89
Belgium	36	1.50	16.94	−13.55	−0.58	3.68
Greece	37	1.23	20.65	−16.52	−0.66	3.35
Romania	38	1.11	22.89	−18.31	−0.71	3.17
Iraq	39	0.78	32.57	−26.06	−1.01	2.86
Nigeria	40	0.59	43.06	−34.45	−1.31	2.49
Kuwait	41	0.24	105.85	−84.68	−2.78	0.50
Korea, Dem. Rep.	42	0.76	33.43	−26.74	−0.86	2.35
Philippines	43	0.91	27.92	−22.33	−0.70	2.42
Chile	44	0.95	26.74	−21.39	−0.62	2.30
Israel	45	1.37	18.54	−14.84	−0.43	2.48
Austria	46	1.37	18.54	−14.84	−0.42	2.38
Qatar	47	0.22	115.48	−92.38	−2.58	0.21
Syrian Arab Republic	48	0.85	29.89	−23.91	−0.66	2.11
Colombia	49	1.04	24.43	−19.54	−0.53	2.19
Belarus	50	1.33	19.10	−15.28	−0.39	2.18
Libya	51	0.14	181.47	−145.17	−3.59	−1.12
Portugal	52	1.61	15.78	−12.62	−0.30	2.09
Finland	53	1.57	16.18	−12.95	−0.30	2.02
Turkmenistan	54	0.22	115.48	−92.38	−2.09	0.17
Hungary	55	1.27	20.00	−16.00	−0.36	1.88
Serbia	56	1.29	19.69	−15.76	−0.34	1.79
Bulgaria	57	1.28	19.85	−15.88	−0.33	1.75
Norway	58	1.63	15.59	−12.47	−0.26	1.81
Morocco	59	1.29	19.69	−15.76	−0.32	1.72
Sweden	60	1.38	18.41	−14.73	−0.30	1.72
Denmark	61	1.54	16.50	−13.20	−0.25	1.67

Rank: Country rank in CO2 emissions, $P_{gasoline}$: p/l gasoline in USD, % $P_{gasoline}$ rise: % p/l rise due to tax, % reduction D: Induced demand reduction, CO_2 reduction: CO_2 reduction due to tax, CO_2 budget: New CO_2 budget

Table B11: Uniform price with base year 2010, +2 °C with 50% probability

Country	Rank	$P_{gasoline}$	% rise $P_{gasoline}$	% reduction D	CO_2 reduction	CO_2 budget
China	1	0.99	28.50	−22.80	−123.39	417.81
United States	2	0.56	50.38	−40.31	−95.38	141.27
India	3	1.09	25.88	−20.71	−35.14	134.54
Russian Federation	4	0.89	31.70	−25.36	−19.90	58.57
Japan	5	1.42	19.87	−15.90	−7.63	40.37
Germany	6	1.56	18.09	−14.47	−4.42	26.14
Iran, Islamic Rep.	7	0.10	282.14	−225.71	−52.90	−29.46
Canada	8	0.76	37.12	−29.70	−6.08	14.39
United Kingdom	9	1.44	19.59	−15.67	−3.17	17.06
Korea, Rep.	10	1.51	18.68	−14.95	−3.48	19.79
Mexico	11	0.74	38.13	−30.50	−6.76	15.40
South Africa	12	0.87	32.43	−25.94	−6.30	17.98
Italy	13	1.57	17.97	−14.38	−2.39	14.26
Saudi Arabia	14	0.16	176.34	−141.07	−26.86	−7.82
Indonesia	15	0.50	56.43	−45.14	−8.03	9.76
Brazil	16	1.26	22.39	−17.91	−5.05	23.15
Australia	17	0.74	38.13	−30.50	−4.67	10.63
France	18	1.52	18.56	−14.85	−2.20	12.61
Spain	19	1.23	22.94	−18.35	−2.03	9.03
Ukraine	20	0.88	32.06	−25.65	−3.21	9.29
Poland	21	1.43	19.73	−15.78	−2.05	10.95
Turkey	22	1.87	15.09	−12.07	−1.47	10.74
Thailand	23	0.87	32.43	−25.94	−3.14	8.97
Kazakhstan	24	0.83	33.99	−27.19	−2.77	7.42
Malaysia	25	0.53	53.23	−42.59	−3.79	5.10
Egypt, Arab Rep.	26	0.49	57.58	−46.06	−3.87	4.53
Argentina	27	0.78	36.17	−28.94	−2.14	5.26
Venezuela, RB	28	0.02	1410.69	−1128.56	−93.35	−85.08
Netherlands	29	1.68	16.79	−13.44	−1.00	6.46
United Arab Emirates	30	0.45	62.70	−50.16	−3.45	3.42
Pakistan	31	0.84	33.59	−26.87	−1.78	4.84
Vietnam	32	0.80	35.27	−28.21	−1.74	4.42
Uzbekistan	33	1.35	20.90	−16.72	−0.72	3.57
Czech Republic	34	1.37	20.59	−16.48	−0.75	3.83
Algeria	35	0.34	82.98	−66.39	−3.36	1.70
Belgium	36	1.50	18.81	−15.05	−0.67	3.79
Greece	37	1.23	22.94	−18.35	−0.65	2.90
Romania	38	1.11	25.42	−20.33	−0.66	2.57
Iraq	39	0.78	36.17	−28.94	−1.36	3.34
Nigeria	40	0.59	47.82	−38.26	−1.24	2.00
Kuwait	41	0.24	117.56	−94.05	−3.61	0.23
Korea, Dem. Rep.	42	0.76	37.12	−29.70	−0.87	2.06
Philippines	43	0.91	31.00	−24.80	−0.83	2.52
Chile	44	0.95	29.70	−23.76	−0.70	2.26
Israel	45	1.37	20.59	−16.48	−0.48	2.42
Austria	46	1.37	20.59	−16.48	−0.45	2.29
Qatar	47	0.22	128.24	−102.60	−2.97	−0.08
Syrian Arab Republic	48	0.85	33.19	−26.55	−0.67	1.86
Colombia	49	1.04	27.13	−21.70	−0.67	2.43
Belarus	50	1.33	21.21	−16.97	−0.43	2.12
Libya	51	0.14	201.53	−161.22	−3.90	−1.48
Portugal	52	1.61	17.52	−14.02	−0.30	1.85
Finland	53	1.57	17.97	−14.38	−0.36	2.17
Turkmenistan	54	0.22	128.24	−102.60	−2.23	−0.06
Hungary	55	1.27	22.22	−17.77	−0.37	1.71
Serbia	56	1.29	21.87	−17.50	−0.33	1.55
Bulgaria	57	1.28	22.04	−17.63	−0.32	1.51
Norway	58	1.63	17.31	−13.85	−0.32	2.02
Morocco	59	1.29	21.87	−17.50	−0.36	1.71
Sweden	60	1.38	20.44	−16.36	−0.35	1.80
Denmark	61	1.54	18.32	−14.66	−0.28	1.62

Rank: Country rank in CO2 emissions, $P_{gasoline}$: p/l gasoline in USD, % $P_{gasoline}$ rise: % p/l rise due to tax, % reduction D: Induced demand reduction, CO_2 reduction: CO_2 reduction due to tax, CO_2 budget: New CO_2 budget

C Formulas

D Carbon budget calculation

We obtain excess emission EE by subtracting the remaining emission budged RE_B from the total emission forecast TEF until 2050.

$$EE = TEF - RE_B$$

RE_B is the difference between the 1640 Gt CO_2 budget from 2000 to 2050 and the realized worldwide emissions ER in the period 2000 to the end of 2008. To obtain RE_B the resulting difference is multiplied by 0.9 because the analyzed sample encompasses 61 countries that cover 90% of worldwide emissions in 2008. Realized worldwide emissions are taken from the WDI and are identical to the the sum of emissions across all countries i between 2000 and 2008.

$$ER = \sum_{i}^{N} \sum_{t=2000}^{T=2008} E_{it}.$$

The compact definition of the remaining emission budged is therefore

$$RE_B = (E_B - ER) \cdot 0.9$$

The total emission forecast equals the sum of the $i = 61$ country emission forecasts

$$TEF = \sum_{i}^{61} EF_i$$

We adopt a simple rule for the emission forecasts by assuming that counties emit every year until 2050 their 2008 emissions $\overline{EA}_{i,t}$ until 2050, therefore

$$EF_i = \sum_{t=2009}^{T=2050} \overline{EA}_{i,t}$$

With these parameters at hand only the average energy price per country and the long-run price elasticity of energy demand is necessary to calculate the required energy tax τ. As a proxy for the average energy price we take the pump gasoline price P_i in every country. According to Flood et al. (2007) the consensus in the literature is that the long-run price elasticity ϵ of gasoline demand is around -0.8 and differences between countries are typically moderate. The elasticity $\epsilon = -0.8$ for example also in line with Hausman and Newey (1995) and Kilian and Murphy (2013). Given the emission forecast EF_i from 2009 to 2050, we can equate excess emissions to the sum of reduced energy consumption due to the energy price rise as shown in equation 1. This equation can now be rearrange to obtain τ in equation 2.

$$-EE = \sum_{i}^{N} \frac{EF_i \cdot \tau \cdot \epsilon}{P_i} \quad (1)$$

$$P_T = \frac{-EE}{\sum_{i}^{N} \frac{EF_i}{P_i} \epsilon} \quad (2)$$

τ represents the carbon tax for the average energy unit. The tax τ for the average energy unit can easily be transformed into a carbon tax, therefore we use these expressions interchangeably. Since we have approximated the average energy price by the gasoline price we use the conversion factor CF of gasoline to calculate how many consumed liters of gasoline produce 1 ton of CO_2. Therefore, the price for a ton of carbon dioxide P_{CO_2} can be calculated as:

$$P_{CO_2} = \tau \cdot CF \quad (3)$$

Table A3 shows the numerical values of the variables used and calculated that lead to the results presented in Table 2. Table A4 and Table A5 are linked similarly but have as base year 2010.

Table 2 shows that pump gasoline prices vary substantially across nations. Therefore, the percentage price rise induced by a uniform carbon tax τ varies accordingly. Based on the percentage price increase the reduction in gasoline demand is calculated using the price elasticity of gasoline demand. The calculated reduction can subsequentlly be used to obtain the CO_2 reduction. The implied CO_2 budget results from the difference between the emission forecast and the CO_2 reductions on the country level.

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