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Equity and the Convergence of Nationally Determined Climate Policies

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Abstract

By adopting the Paris Agreement on climate change the world community has agreed on global goals for climate policy. However, by relying on voluntary contributions and respecting "national circumstances" it does not ensure efficient and equitable country policies. To derive guidelines for a fair burden sharing between countries the paper applies welfare theory and combines it with general equity principles. The procedure selects those "national circumstances" which are suitable for internationally acceptable policies. The concept is then compared to policies formulated by purely selfish countries. A convergence process closing the gap between country contributions and the optimum international climate policy is developed. It is argued that equity-based signals can be a forceful means supporting this process.

Keywords: Climate policy, equity, climate agreements, social welfare.

JEL Classification: *Q54, Q56, D63, H40*

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1 Introduction

There is broad public consensus that the Paris Agreement on climate change constitutes a milestone in international environmental policy. For the first time in history the world community unanimously agreed on limiting global warming by adopting specified procedures. Yet, concrete climate policy measures are not implemented on a global level but formulated in terms of independent country contributions, which may be called the "bottom-up" approach to climate policy. It encourages broad policy participation but has been criticized as being neither efficient nor equitable.[1] Indeed, current policy contributions are not efficient because countries' marginal abatement costs are not equalized and the internationally agreed temperature targets are not reached. This contrasts with the principles of environmental economics, according to which an efficient policy would set a unique world carbon price or limit the quantity of world carbon emissions on an optimal level. Moreover, policy contributions are not equitable because certain countries are significantly more ambitious in emission abatement than others, reflecting that no general guidelines or benchmarks for burden sharing have been implemented so far.

It is important to analyze the gap between the currently agreed and an efficient climate policy. Advising governments to adopt optimal policies may be called the "top-down" approach to environmental policy. It is correct according to theory but risks to ignore all the problems associated with getting the policy approved by the political process; with global warming this even includes international negotiations. Hence, the top-down procedure usually misses the transition costs of changing an economy to a new equilibrium. Difficulties typically arise because of policy induced changes in the sectoral structure and the income distribution. In fact, climate policy affects the different economic sectors and household types in an asymmetric manner. Public perception is often biased, however, see Sterner (2011).[2] Already on a national level, equity (or perceived equity) is a prime concern when

[1] Concerns have been expressed by Cramton et al. (2015), Stiglitz (2015), Weitzman (2014), and Gollier and Tirole (2015).

[2] While it is widely believed that energy taxes have a regressive impact and mostly hurt the poor the contributions in Sterner (2011) show that fuel taxation is a progressive policy particularly in low income

crafting environmental policy. Accordingly, green tax reforms and emission trading systems usually contain a redistribution component favoring those groups which are mostly affected by policy. On the international level, distributional problems are only compounded. This especially holds true for climate change and climate policies, which have both a major impact on world income distribution. Without any policy, less developed and vulnerable countries will suffer disproportionately.[3] With stringent climate policies, carbon-intensive countries have to bear significant costs to decarbonize their economies.

Current country contributions to international climate policy are closely related to domestic costs and benefits of climate policy; the different "national circumstances" have been stressed by many parties of the Paris Agreement (UNFCCC 2015). Given the rules of the United Nations, policy participation is voluntary, every country can decide to stay outside of an agreement or to withdraw from it. There is no invisible hand guiding a country to accept a solution which is efficient on the global level but perceived as unfair at the country level. This naturally suggests to start with a bottom-up procedure for formulating international policy. Yet, to reach convergence between the countries and to meet global temperature targets, a powerful international coordination mechanism is needed. The paper argues that equity can provide the guidelines for this coordination.

The Kyoto protocol failed because it prescribed uneven burden sharing; it missed to include all major emitters in a meaningful way. If equity principles are successfully applied, they can form a major driver to close the gap between the currently envisaged and the optimum in international climate policy.[4] Ideally, it will become possible to extract those national circumstances which are generally acceptable for fair burden sharing. International climate policy is indeed an important equity issue as much as it is an efficiency problem.[5] An indication that this might set the direction is the fact that the concept of equitable

countries.

[3] Bretschger and Valente (2011) derive the macreconomic impact of climate change in a dynamic setting.

[4] See also Pierce (1988) for a general evaluation of equity in the sustainability debate.

[5] The Kyoto protocol was not able to solve the coordination problem, major emittors were even not included in the agreement at all.

burden sharing appears prominently in the text of the Paris Agreement.[6] The paper aims to explain the mechanics of a policy convergence process and the role of equity-based signals in an international context, which may affect public opinion and policy decisions at the country level.

Providing economic guidelines for solving equity problems is not the usual task of deriving empirically testable and potentially refutable propositions from first principles. Here, the economic approach does not seek to explain observable events but rather to evaluate the desirability of alternative policy choices. To do so, welfare theory can be applied, embedding equity concerns in social welfare functions. An alternative concept is the Pareto condition which was put forward in the climate context under the label "international Paretianism" (Posner and Weisbach 2012). Because not a single country should lose from international climate policy the concept implies a substantial income redistribution from climate vulnerable and poor countries to oil-extracting countries. This has been criticized as indefensible, confirming the importance of distribution and fairness for international climate policy.

The present paper introduces and discusses welfare functions in order to organize, formalize, and synthesize equity consideration in formal theory.[7] To deal with this aspect of climate policy it is convenient to use emission quantities rather than prices, i.e. to focus on country carbon budgets.[8] By focusing on equitable climate policy the contribution is

[6]See the preamble paragraph 3, saying: "In pursuit of the objective of the Convention, and being guided by its principles, including the principle of equity and common but differentiated responsibilities and respective capabilities, in the light of different national circumstances," and in Article 4 paragraph 1 stating: "In order to achieve the long-term temperature goal set out in Article 2, parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with the best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty." (UNFCCC 2015)

[7]Fankhauser et al. (1997) and Anthoff and Tol (2010) use a similar procedure for environmental valuation.

[8]Concrete numbers can e.g. be taken from Meinshausen et al. (2009). It is known that Cramton et al. (2015), Stiglitz (2015) and Weitzman (2014) have argued it would be easier to negotiate a uniform carbon prices, but negotiating countries will always consider how each instrument affects their carbon emission potential for the future; Gollier and Tirole (2015) state that either a carbon tax or a global cap would constitute a formidable achievement.

related to Lange et al. (2007), Mattoo and Subramanian (2010), and Bretschger (2013), where specific rules for burden sharing based on equity principles are derived. Bretschger and Mollet (2015) apply the theory and provide country calculations and comparisons to carbon tax solutions. Overviews on the use of equity principles are given in Rose et al. (1998), Konow (2003) and Grasso (2007), applications to climate and environmental economics are provided in Cazorla and Toman (2000), Metz (2000), Grasso (2007), Page (2008), Johansson-Stenman and Konow (2010), and Bretschger (2015). Egalitarian access to carbon space as an equity concept was put forward by BASIC (2011) and Bode (2004).

The remainder of the paper is organized as follows. Section 2 analyses different welfare function. In Section 3, I develop a workable concept for the equity status of a country. Section 4 studies country policies and introduces policy convergence mechanisms. Section 5 concludes.

2 Welfare optimum

According to theory, efficiency of global climate policy is achieved when marginal benefits of policy equal marginal cost, provided that risk is considered in an adequate way and future generations are weighted in an appropriate manner. On a more pragmatic level, efficiency of climate policy is defined by the temperature goals that have already been established in the Paris climate agreement. Applying climate physics one can derive the world carbon budgets which are compatible with the temperature goals (Meinshausen et al. 2009). However, the really difficult policy issue of international burden sharing in climate policy is not solved by fixing world emission targets. This is a distributional problem, for which economics does not provide a general theory. The theory on coalition building assumes selfish nations entering a multilateral bargaining process, which is a prominent and natural application of an important field in economics. This paper proposes to complement the literature on climate policy with a different approach, relying on welfare theory. If we are willing to apply a general welfare function we may define an equitable climate policy as the distribution of the world carbon budget to the different countries providing maximum welfare.[9] The approach adopted here relates to standard welfare theory and allows discussing the different proposals for climate policy using specific parameter values.

Of course, any welfare model involves value judgements but without these, obtaining an acceptable welfare ordering may not be possible at all. According to the standards of basic welfare economics, equity concerns can be conveniently embedded in social welfare functions through an appropriate choice of the functional form. If the form is established, the most desirable carbon budget distribution is the one that maximizes social welfare. Optimality will assure equal marginal contributions to social welfare across countries and hence identical equity weights.

To determine an optimum for this wealth distribution problem I formulate a general welfare function and explain the role of equity in this context. The welfare function used below measure welfare generated by carbon budget. It combines the welfare levels of individual countries to create a ranking of different states of the world from the point of view of global climate policy. Formally, aggregate welfare W with N different countries $(i = 1, 2, ...N)$ is given by

$$W = W(Z_1, Z_2, ...Z_N) \tag{1}$$

where Z_i is the optimal carbon budget of country i and budgets add up according to

$$\sum_{i=1}^{N} Z_i = Z \tag{2}$$

with Z denoting the world carbon budget that is available for meeting the internationally agreed temperature target. To find the optimum distribution of the world carbon budget, (1) has to be maximized under the restriction (2).

A more specific but still very general specification of function (1) is given by the CES form, reading

$$W = \frac{\sum_{i=1}^{N} b_i (Z_i)^{1-\sigma} - 1}{1 - \sigma} \tag{3}$$

[9] When a global carbon market is established or taken as a reference point, carbon has a uniform price so that the value of a country carbon budget can be assessed like with any other asset. Then, the country carbon budget can be analyzed like any other component of household wealth.

where the b_is are the distribution parameters ($\sum_{i=1}^{N} b_i = 1$) and σ serves as a parameter measuring inequality aversion; the larger is σ the more we are concerned with equality. Using specific values for σ enables us to discuss different welfare concepts in detail and to determine an appropriate form for the issue at hand.

Assuming $\sigma = 0$ yields the well-known utilitarian welfare function, which in the present context says that welfare of a country is a perfect substitute to welfare of another country. Put differently, welfare of each country is given equal weight and country welfares are simply added up. As a consequence, world welfare is constant even when welfare of a country becomes zero as long as another country can increase its welfare to the same extent. Acknowledging the high importance of climate vulnerable and poor countries in the international climate negotiations process this variant has to be dismissed as a useful guideline for international climate policies.

By setting $\sigma = \infty$ we obtain the maximin welfare function, sometimes associated with the welfare concept of Rawls (Rawls 1971). In this case, to calculate global welfare, only the welfare of the country with the lowest budget matters. Hence, this is the variant with the highest concern about equality of the countries' carbon budgets. Accordingly, the budget allocation yielding highest welfare is the egalitarian distribution. It has been argued that the egalitarian distribution would be the outcome when abstracting the welfare guideline from current economic conditions because these largely affect individual views on equity. To illustrate the idea, a virtual "veil of ignorance" could be imagined so that countries would not know their initial condition and the question then would read what distribution of carbon budgets they would agree to *ex ante* if they only found out the realized country position *ex post*. Rather than discussing whether the veil of ignorance has a specific merit in the current global climate debate I prefer to stress that the egalitarian distribution is not necessarily the most equitable solution. Indeed, fairness requires comparing "like with like," which means that countries' circumstances with respect to factors such as income, size, merits, costs etc. have to be considered as well. A purely egalitarian distribution may give rise to envy as it disregards countries' specific conditions which may make it especially difficult or easy to go along with a restricted carbon budget. Hence, the consideration of country specific conditions may help to minimize envy and by this increasing acceptance of overall policy. But in order to serve the purpose, the crucial question is whether the country specific conditions are generally accepted as valid by the other countries.

The consideration of a broader set of country conditions under equity aspects becomes possible when adopting the intermediate value $\sigma = 1$ in (3), yielding the Bernoulli-Nash welfare function, reading

$$W = \prod_{i=1}^{N} (Z_i)^{b_i} \tag{4}$$

where $0 < b_i < 1$ represents the elasticity of welfare with respect to the budget of country i. Here, aggregate welfare is assumed to be increasing and concave in the countries' carbon budgets, which appears to be a natural assumption. Moreover, with the multiplicative form, the marginal welfare of a country's budget is increasing in the budget of the other countries. Finally, global welfare is zero when a country receives no budget at all, which is in accordance with the intentions of the United Nations climate convention. An egalitarian distribution materializes when $b_1 = b_2 = ... = b$. But the egalitarian solution only emerges when no country specific conditions are generally accepted or when country specific conditions exactly offset each other.

To include country conditions and to apply specific equity concepts involves including a set of additional parameters. For equity reasons, elasticities b_i may become unequal between countries. I assume b to be endogenous and to be determined by the functional form

$$b_i = B \cdot s_i \cdot (V_i)^{\alpha} \tag{5}$$

where $B > 0$ is a scale parameter and $0 < s_i < 1$ is the share of country i of world population; $(V_i)^{\alpha}$ represents country i's equity status where V is an underlying equity measure and $0 \leq \alpha \leq 1$ reflects that the equity status is an increasing and concave function of V. Now, starting from an egalitarian budget distribution, a marginal redistribution of carbon budget from a country with low b to a country with higher b would increase overall welfare. To motivate (5), it seems natural to assign a rising marginal contribution for countries with increasing population size. Moreover, when fairness considerations are assumed to have an impact on optimal policy choices, the marginal impact on aggregate welfare also depends on the equity status of a country. Of course, equity status V has to be determined in further detail, which will be the subject of the next section.

To find the optimum distribution of world carbon budget, (4) has to be maximized under the restriction (2) and using (5), which yields for two specific countries i and $i\prime$

$$\frac{Z_i}{Z_{i'}} = \frac{b_i}{b_{i'}} = \frac{s_i}{s_{i'}} \left[\frac{V_i}{V_{i'}}\right]^{\alpha}. \tag{6}$$

From (6) we can derive several results. First, the relative carbon budget shares between two countries, $b_i/b_{i'}$, depend *ceteris paribus* linearly on the countries' relative size, $s_i/s_{i'}$, an outcome which appears very plausible and thus broadly acceptable. To determine the relevant size for climate policy, the size of the population is the natural candidate. Second, the budget share of a country is an increasing and concave function of its relative equity status, $V_i/V_{i'}$. Third, special equity cases are given by $\alpha = 1$, where the relative shares rise linearly with equity, and $\alpha = 0$, where the share is independent of the specific equity variable. In the latter case, we get from (6) $Z_i/Z_{i'} = s_i/s_{i'}$ so that every individual in any country receives an equal carbon budget, the well-known notion of an "egalitarian access to carbon space."[10] Fourth, to determine the different V_is, one can adopt either a (world) planner solution or a country-based procedure. The former is a "top-down" approach, which usually provides the normative guideline for policies; it is discussed in the next subsection. The latter is the current procedure of international climate policy, where countries announce their climate policies, and hence their implicit carbon budgets, individually and in a "bottom-up" manner; this will be discussed afterwards.

[10] see BASIC (2011)

3 Equity Status

I now discuss the determination of the equity variable V as used in Eqn. (5). There are several useful guidelines for the procedure. First, we have to concentrate on equity measures which are already broadly accepted on a national level, for example in national tax and subsidy legislation. Second, the used measure has to be simple and replicable, because political messages have to be concise. There is in general no space for overly complicated constructions of complex economic decision models, even if they highlight the climate problem in a detailed manner. Third, the chosen metric must be measurable, verifiable and universal. Only a variable fulfilling these criteria is suitable for international policy making, because policy has to be transparent and ready to be implemented. Finally, the discussion should be related to the concept of "Common but Differentiated Responsibilities" which has become the central guideline for burden sharing in the UN Climate Convention. Let us thus discuss possible equity candidates in turn.

A first possible anchor for equity in relation to carbon policy may be the country's capacity or its "ability to pay," usually measured by income per capita (Y/L). In fact, as a country should contribute more to international policy the higher is its capacity; the equity measure V would have to be inversely related to income per capita ($= L/Y$). Put differently, the richer is a country on average, the lower would become its carbon budget in a welfare optimum. It has been evaluated whether income per capita alone would be a suitable indicator of equity. It is generally found that income is important but does not cover all the relevant aspects, which are contained in the following principles. A second element to determine equity is the notion of sharing the cost that carbon policy imposes on countries in a fair way. Countries with the highest current carbon budget per capita have to redirect their economies in the most stringent manner. This suggests using emissions per capita (E/L) as an element of V: the higher current emission per capita, the larger the policy cost to redirect the economy and the higher the equitable carbon budget.

A third equity principle, broadly used in the discussion of wage and income distribution, is the aspect of merit or desert. It is generally accepted, that persons or firms with special and achievement deserve higher compensation in the optimum. Accordingly, achievement in carbon policy should also be rewarded. Single major innovations might be considered but might be difficult to assign to specific countries. Moreover, on a country level, the adoption of innovations is more important. Hence, a possible candidate for an equity measure would be carbon efficiency, GDP per average carbon emissions (Y/E). Of course, higher carbon efficiency helps to reduce energy costs. But this is not sufficient as a motivation for individual action, because in this case the climate problem would be easily solved. There are huge positive exernalities from carbon efficient solutions,[11] which merits a compensation for the efforts by an increased carbon budget.[12]

I have argued in a previous paper[13] that the combination of these three major principles provides interesting insights and results in a surprising simplification. Specifically, using equal weights for the three variables and the multiplicative form for interlinking them, equity status becomes

$$(V_i)^{\alpha} = \left[\frac{L_i}{Y_i} \cdot \frac{E_i}{L_i} \cdot \frac{Y_i}{E_i}\right]^{\alpha} = 1 \tag{7}$$

which says that in this case equity becomes independent of any macroeconomic parameter and even of the impact parameter α.[14] It suggest an egalitarian distribution of the carbon budget per capita, without imposing it from the beginning but rather deriving it from three basic principles.

However, the analysis of an egalitarian distribution of carbon space is purely static and misses the dynamic perspective, a constitutive element of sustainable development. In the context of carbon emissions, the dynamic aspect is reflected by technical progress

[11] As an aexample, it has been calculated that the realisation of all the intrended contributions of the countries to global climate policy will cause a major downward shift of prices of green technologies which will benefit the whole world economy.

[12] It might sound paradox to reward a carbon efficient country with a higher carbon budget, but the budget is the only means for compensation available in this approach. On the permit market, the budget can be sold, if unused, so that it becomes equal to any form of compensation.

[13] see Bretschger (2013)

[14] In the case of unequal weights of the parameters equity status and carbon budgets can still be calculated, see the ETH climate calculator at www.ccalc.ethz.ch.

and increasing carbon efficiency. Each year, efficiency of the use of fossil fuels increases by more than one percent. Relating this finding to a fair burden allocation suggests that later developing countries have the advantage of having access to technologies with higher carbon efficiency. Comparing "like with like" means that *ceteris paribus* it is more difficult to avoid greenhouse gas emissions when only few alternatives for energy conversion are available.

Over time, emissions have been increasing with economic activities and, especially, with transport infrastructure and buildings. The recent slow down or trend reversal in some countries is already accommodated by the merit principle. Hence, even if simplistic, it appears warranted to use emissions per capita as an indicator of the technology alternatives at the time of energy investments. As a consequence, the equity-based distribution can then directly be compared to other concepts such as the tax solution with domestic use of tax revenues, see Bretschger and Mollet (2015). It results that the main equity variable is emissions per capita and that its impact on the countries' carbon budget is given by the size of the parameter α, according to

$$\frac{Z_i}{Z_{i'}} = \frac{s_i}{s_{i'}} \left[\frac{(E/L)_i}{(E/L)_{i'}} \right]^{\alpha} \tag{8}$$

which shows a nonlinear relationship between country budgets and emissions per capita, see Bretschger (2013) for further explanations.

4 Country Policies and Convergence

The derivation of an equity-based carbon budget, resulting in quantity Z_i for each country i, represents the top-down approach to climate policy, reflecting aggregate welfare. In contrast, the Paris Agreement builds on a bottom-up process of country specific contributions to international climate policy. The construction of the agreement is thus vastly different from the Kyoto Protocol, which contained specific emission reductions. By adoption of the agreement, the previous distinction between developed and developing countries has been replaced by differentiated individual contributions and thus by a broader approach to burden sharing. It is viewed as highly positive that so many countries participated in the process of formulating national policy plans. However, the aim of a fair international distribution of policy cost was not a central focus of the negotiations. Accordingly, the current climate treaty does not contain a reference to a well-defined carbon budget allocation (nor to a uniform carbon price). The individual contributions are not listed and assessed according to common objective criteria. In this sense, the Paris Agreements is not a final result but rather a start for a long and dynamic process.

When the voluntary contributions should develop over time it is certainly worth looking into the dynamics in more detail. The problem is that the periodic reviews of countries' climate policies are separated per country and not formulated according to generally accepted standards. In particular, Article 4 paragraph 3 of the Paris Agreement lays out: "Each Party's successive nationally determined contribution will represent a progression beyond the party's then current nationally determined contribution and reflect its highest possible ambition, reflecting its common but differentiated responsibilities and respective capabilities, in the light of different national circumstances" (UNFCCC 2015). The country-specific circumstances are thus prominently represented in the current agreement, much more than an overarching logic of burden sharing. It should be noted again, therefore, that the current contributions to climate policy are neither efficient (too little ambition) nor fair (individual countries go much further than others) so that there remains a large potential for improvement. I argue in the following that an international convergence to a common metrics in climate policy would be highly helpful to increase world efforts in emission abatement.

In the absence of international linkages or coordination mechanisms, the different negotiating parties act in their own interest. Specifically, for each country i, the optimal policy equalizes marginal benefits and marginal damages of carbon emissions E_i at the country level. If carbon emissions end at point in time T, the nationally determined carbon budget Z_{in} is then given by $Z_{in} = \sum_{t=0}^{T} E_{it}$ which will, in general, be higher than the equitable country budget Z_i. The reason is that Z_{in} is determined by factors affecting only *domestic* benefits B and *domestic* damage D, while the externalities imposed on other countries are disregarded. Figure 1 shows optimum national emissions E_i when marginal damages D'_i and benefits B'_{i1} are equal, with $B''(E_i) < 0$ and $D''(E_i) > 0$.

**** Figure 1 ****

(about here)

To specify the D'-function we observe that domestic damages from carbon use D arise in the form of regional pollution, where the highest impact is air pollution, and in the form of self-induced global warming, that is for the part of climate change a country is directly responsible for. The latter can be significant for big countries but approximates zero for small countries. To locate the position and the shape of the B'-function we note that the use of fossil fuels (causing carbon emissions E) has a direct benefit in consumption and production, e.g. for transportation and heating. Decreasing marginal benefit (utility) yields the downward-sloping B'-curve in Figure 1. The curve is shifted by several factors affecting marginal benefits. Technical progress A_i may reduce the marginal benefits over time when less polluting technologies become available. In addition, innovation activities increase with the stringency of international climate policy because of induced innovation; as a measure for international climate policy I use the sum of nationally determined carbon budgets $Z_n = \sum_{i=1}^{N} Z_{ni}$. Hence, A_i is assumed to increase with time t ($\partial A_i/\partial t > 0$) and with shrinking Z_n ($\partial A_i/\partial Z_n < 0$); in both cases, the B' curve in Figure 1 is shifted downward, e.g. from B'_{i1} to B'_{i2} and emissions are reduced from E_{i1} to E_{i2}. In addition, fossil fuel use has an indirect benefit when we assume that individual preferences refer to a national or international average behavior. On the one hand, to moderate the discrepancy between rich and poor population, low fuel prices often turn out to have a "social mollifier" function. Specifically, they are used in oil-extracting countries to stabilize political systems and in oil-importing countries to allow for mobility and heating on all income levels.[15] On

[15] Fossil fuels are subsidized in many oil-rich economies, while political resistance against raising fuel prices in the other countries is proof of high consumer rents of fossil use at the expense of the environment.

the other hand, governments and voters may want to avoid international political exposure when national climate policies are lagging behind international standards (if they exist and are publicly known). In particular, if it happened that a common metrics in international climate policies is implemented, a country could identify the gap between its intended policy and the policy required by international standards. It then may find it politically undesirable to stay below the efforts of comparable countries and would react when other countries move towards the standards, adopting more stringent climate policies, lowering world budget Z_n. A lower Z_n would then reduce the benefit of own pollution ($\partial B'/\partial Z_n > 0$), shifting the B' curve downward and reducing country emissions. In the same way, each increase in a country's contribution would exert an externality on the benefits of other countries' emissions, shifting their B' curves downward. This circle of international policy linkages would speed up the process of decarbonization.

For a single country i the domestic optimum for E_i is given when marginal damages of carbon use are equal to marginal costs, yielding point E_{i1} in Figure 1 and the analytic expression

$$B_i'[E_{i1}|A_i(t, Z_n), Z_n] = D_i'(E_{i1}). \tag{9}$$

The challenge for future policy is given by the gap between planned and required carbon budgets, i.e. the inequality

$$Z_n = \sum_{i=1}^{N} Z_{ni} = \sum_{i=1}^{N} \sum_{t=0}^{T} E_{it} > Z \tag{10}$$

which says that the currently planned global carbon budget is too high compared to the efficient budget.

Following the present approach, the change of emissions can be obtained by taking the total differential of Eqn. (9) and rewriting the terms which yields

$$dE_i = \frac{1}{\underset{+}{\underbrace{D''(E) - B''(E)}}} \left[\underset{-}{B_i''(A_i)} A_i'(t) dt + \{ \underset{+}{B_i''(A_i) A_i'(Z_n)} + \underset{+}{B_i''(Z_n)} \} dZ_n \right], \tag{11}$$

where $\partial D'/\partial E = D''(E) > 0$, $\partial B'/\partial E = B''(E) < 0$, $\partial B'/\partial A = B_i''(A_i) < 0$, $A_i'(t) > 0$, $A_i'(Z_n) < 0$, and $B''(Z_n) > 0$. According to this specification, technical progress ($dt > 0$)

and aggregate climate efforts ($dZ_n < 0$) act as impulses for lowering a country's emissions ($dE/dt < 0$, $dE/dZ_n > 0$) while the terms for international linkages $A_i'(Z_n)$, i.e. innovation induced by climate policy, and $B''(Z_n)$, i.e. decreased domestic benefit due to international climate policy, act as propagation mechanisms. The larger is the propagation of impulses from technology and international policy, the faster becomes the momentum of national climate policies. With the current climate agreement, however, the channel operating through $B''(Z_n)$ is completely absent, which means that emission reduction dE_i necessarily becomes smaller.

**** Figure 2 ****

(about here)

Different world emission paths over time are illustrated in Figure 2. The case of linearly decreasing world emissions E which are compatible with the available carbon budget from now up to 2050 are visualized by the line ending in point A; the grey area represents the total budget Z. With the current planning, however, the world emission path does not exhibit sufficient carbon cuts, which is represented by the line ending in point B in 2030, where the budget would be used up already. If no further mitigation policies are adopted by then, an immediate emission stop or the case for negative emissions would come up in urgency, e.g. massive afforestation, carbon capture and sequestration, and/or use of bioenergy. Still it would be highly uncertain whether this would be fast and effective enough. Hence it appears more promising to continuously bend the emission path downward which is precisely the effect of the analyzed momentum effects. A possible path, exhibiting the impact of momentum triggered by international linkages in international climate policies, is visualized by the curve passing along point C in Figure 2. Increasing speed in carbon emission cuts would in this case lead to an emission path which is compatible with the temperature targets of the Paris Agreement. Of course, any delay in the policy in a first phase has to be compensated by deeper cuts in a second phase because the aggregate carbon budget is given. But, to conclude, the agreement on principles of burden sharing and the application of general metrics for climate policy would be an important step for reaching the temperature targets of the Paris climate Agreement.

5 Conclusions

The present paper has used general welfare theory and equity consideration to derive a scheme for optimal burden sharing in international climate policy. I have argued in favor of applying the Bernoulli-Nash welfare function, with the elasticities yielding countries' optimal carbon budget shares. Shares are endogenously determined by the equity status of the countries. It was argued that the "ability to pay" principle, the "policy cost sharing" principle and the "merit" principle are important for the equity status but can neutralize each other under general conditions. Contrary to these static principles the notion of sustainable development suggests looking at technical progress, providing the result that equitable carbon budgets can be determined as a nonlinear function of per capita carbon emissions.

Efficient and equitable carbon budgets are derived from a top-down approach to climate policy. They can serve as a guideline for future negotiations but do not reflect current policy plans. These are formulated in a pure bottom-up manner, providing voluntary country contributions. The contributions are obtained by plans which are optimal for the single countries but not for the world community as a whole, because international externalities are usually ignored. Technical progress can move the national policies towards more ambitious targets. Due to induced innovation, world emission reductions themselves are a major driver for carbon-saving technical progress. The national policy commitments are expected to further reduce future costs of climate policy by scale and learning effects.

However, the dynamics of the climate policy process are very slow, in particular when international linkages are inactive. When countries are not confident that the other emitters will make significant reduction efforts, they will not be willing to substantially increase their contributions to the global commons. They will rather see free-riding as a legitimate way of protecting their citizens from exploitation by other free-riders. To close the gap between the currently planned policies and the policies needed to meet the agreed temperature targets, the paper argues in favor of finding common metrics for policy assessment. If the metrics are generally accepted and internationally communicated they may induce countries to close their emission gaps in a more rapid manner. If this process of international comparison and policy propagation is effective, it can speed up emission cuts and develop momentum, such that rate of emission reduction is increased over time and the temperature targets can ultimatively be met.

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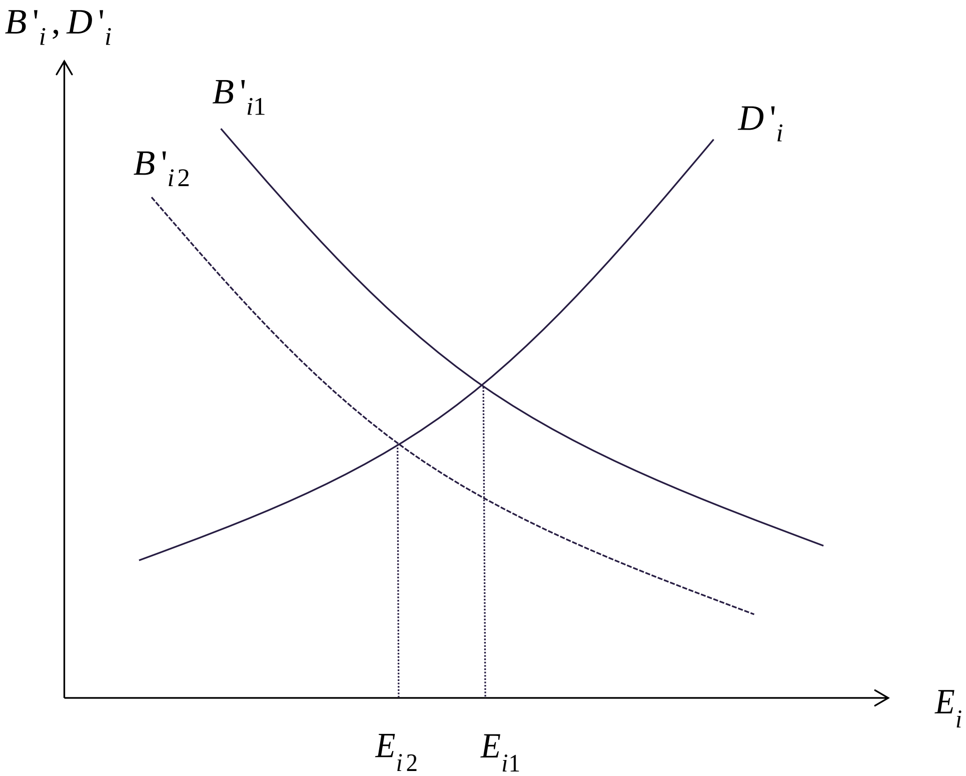

Figure 1

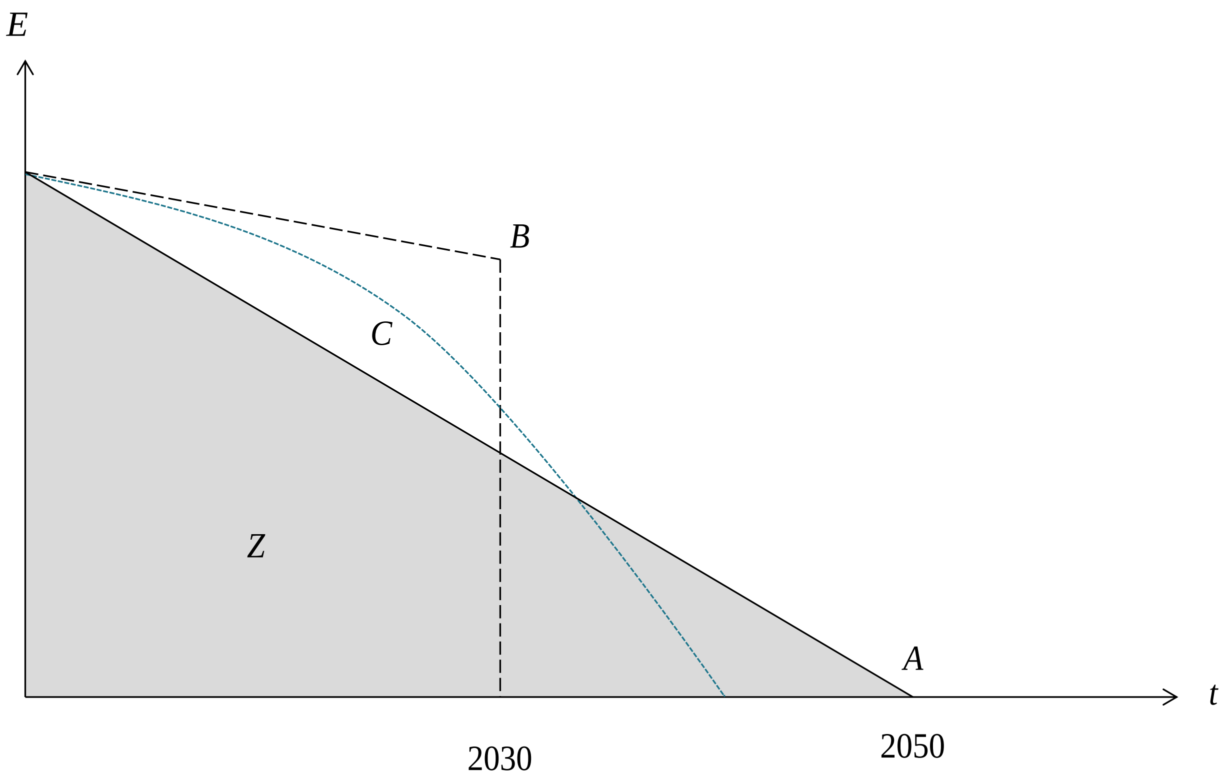

Figure 2

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