Equity in Climate Change
An Analytical Review

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Abstract

How global emissions reduction targets can be achieved equitably is a key issue in climate change discussions. This paper presents an analytical framework to encompass contributions to the literature on equity in climate change, and highlights the consequences—in terms of future emissions allocations—of different approaches to equity. *Progressive cuts relative to historic levels*—for example, 80 percent by industrial countries and 20 percent by developing countries—in effect accord primacy to adjustment costs and favor large current emitters such as the United States, Canada, Australia, oil exporters, and China. In contrast, principles of *equal per capita emissions, historic responsibility,* and *ability to pay* favor some large and poor developing countries such as India, Indonesia, and the Philippines, but hurt industrial countries as well as many other developing countries. The principle of *preserving future development opportunities* has the appeal that it does not constrain developing countries in the future by a problem that they did not largely cause in the past, but it shifts the burden of meeting climate change goals entirely to industrial countries. Given the strong conflicts of interest in defining equity in emission allocations, it may be desirable to shift the emphasis of international cooperation toward generating a low-carbon technology revolution. Equity considerations would then play a role not in allocating a shrinking emissions pie but in informing the relative contributions of countries to generating such a pie-enlarging revolution.

This paper—a product of the Trade and Integration Team, Development Research Group—is part of a larger effort in the department to understand the development implications of climate change mitigation. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at amattoo@worldbank.org.

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Executive Summary

Even as the world contemplates stronger action to reduce CO_2 emissions to prevent catastrophic climate change, how this goal can be accomplished equitably has become central to the debate. This paper presents an analytical framework to encompass the existing contributions to the literature on equity in climate change. It seeks, in particular, to highlight the consequences—in terms of future emissions allocations—of different approaches to equity. The review yields the following conclusions.

There is no denying that today industrial countries have substantially greater per capita CO_2 emissions than developing countries. This wide gap reflects substantially higher usage of energy per capita in industrial countries. There is less agreement on how equity considerations should inform future action on climate change, reflected in the different proposals that have been made.

Four equity-based proposals recur in the literature. These suggest that emissions allocations be: (i) allocated equally on a per capita basis; (ii) inversely related to historic responsibility for emissions; (iii) inversely related to ability to pay; and (iv) directly related to future development opportunities. The case has also been made for adjustment costs to be taken into account in emissions allocations.

Taking account of country-based adjustment costs tends to favor the status quo emissions allocations. The proposals in Stern (2007) and in UNDP (2008), which use 1990 as a base for calculating emissions reductions going forward, are implicitly "grandfathering" existing emissions allocations, and are in spirit attempting to give weight to adjustment costs by softening the impact of emissions reductions on those who have to make the largest reductions. It turns out that even reasonably progressive cuts relative to historic levels—for example, 80 percent by industrial countries and 20 percent by developing countries— in effect accord primacy to absolute adjustment costs. Such proposals therefore favor large current emitters such as the United States, Canada, Australia, the oil exporters and China, at the expense of the emissions frugal.

Other principles of equal per capita emissions, historic responsibility and ability to pay favor some large and poor developing countries such as India, Indonesia, the Philippines, Pakistan and Nigeria. In any purely equity-based approach going forward, these countries would not be required to assume mitigation commitments. China would, however, be required to make cuts because its projected business-as-usual emissions are higher than those of the countries named above and higher than what its allocations would be under these principles.

However, these equity principles would hurt not just industrial countries but other developing countries. Thus, a weakness of these proposals is that each of them would inflict unjustified economic costs on some poor countries that do not receive emissions allocations needed to sustain growth. The reason is that the overall carbon budget must be cut significantly to meet climate change goals and since these equity principles allocate a substantial chunk of the shrunken budget to large and poor countries, there is very little left for the small and poor. In so

far as the allocations provided to the large and poor countries are in excess of their growth needs, they could be seen as largesse unjustified by climate change considerations alone.

The principle of "preserving future development opportunities" is most appealing because it is closest to the notion that developing countries should not be constrained in the future by a problem that they did not largely cause in the past. If we assume that incomes of different countries tend to converge over time, which has some empirical support and normative appeal, then developing countries have the greatest economic opportunities. Preserving these opportunities under current technological options would require emissions allocations to all developing countries close to their projected business-as-usual levels. As a result, this principle minimizes conflicts within developing countries. It also has the virtue of not making climate change an instrument for income redistribution for reasons unrelated to climate change. This principle implies that the burden of meeting climate change goals would fall entirely on industrial countries which would be obliged to make drastic cuts in emissions, especially if China's large business-as-usual emissions have to be accommodated.

Hence, the key point that emerges is that conflicts of interest are both inherent and strong—perhaps irreconcilably so—in discussions of equity in emission allocations. They are inherent because the exercise is about allocating a fixed aggregate carbon budget. They are strong because the budget is not really fixed but shrinking dramatically relative to the growing needs of developing countries. Science demands drastic compression in aggregate emissions in order to keep temperatures below reasonable levels with reasonable probability. Given current rates of technological progress, the available carbon budget is not even adequate to sustain business-as-usual growth rates for developing countries, let alone for the world as a whole. The required cuts would only be small enough to be politically acceptable if there were radical—historically unprecedented—technological breakthroughs that allowed significantly higher levels of growth and energy consumption for given levels of emissions.

It may, therefore, be desirable to shift the emphasis of international cooperation toward generating a low-carbon technology revolution; equity would have a key but different role in shaping such international cooperation. Equity would be less about mediating the allocation of a fixed emissions pie than about informing the contributions of different countries in generating a low-carbon technology revolution so as to enlarge this pie. Such a revolution can transform climate change into a non-zero sum game, offering perhaps the only hope of reconciling the development needs of low-income countries with the climate change goals of humanity.

"…and the awareness
of things ill done and done to others' harm
which once you took for exercise of virtue."
T.S. Eliot, Four Quartets, Little Gidding

I. Introduction

In some fundamental sense, the equity debate in the context of climate change has been an attempt on the part of developing countries to create or instill an "awareness" in industrial economies of the "harm" they are believed to have caused during their remarkable economic and industrial progress beginning with the Industrial Revolution in the late 1700s. Of course, the harm to others from carbon-based progress was largely, and until recently, an unintended consequence (collateral damage) of virtuous industrialization. But instilling this awareness of past ills is nevertheless felt to be critical to generating the right "narrative" so that climate change negotiations going forward can produce equitable outcomes that all countries can live with and hence abide by.

But what are the ills? What is the harm? Should we move beyond notions of "ill" and "harm?" More broadly, how should one think about equity and achieving it going forward? This essay provides an analytical structure to bring together the existing attempts at answering these questions. The literature on equity in climate change is voluminous. This paper will not attempt to cover all the contributions that have been made on equity and climate change but focus on the more important and more recent ones.

At the outset, it is worth asking why equity has acquired such salience in the context of climate change. The chart and table below suggest a reason. Chart 1 plots per capita CO_2 emissions against GDP per capita (PPP) for a sample of fifty countries for the latest year (2008) for which data are available.[1] The chart shows a positive and statistically significant relationship between these two variables: richer countries have substantially greater per capita emissions. Table 1 provides data on energy use (comprising household energy and road travel) per capita for some of the major industrial and developing countries. That many of the developing countries consume a fraction of the energy consumed in the rich world suggests that many energy needs remain unmet: for example, the average Indian's energy consumption is one-twentieth of US levels. That the current distribution of emissions and energy use across the world is highly inequitable is widely recognized. How equity considerations should inform future action on climate change is less clear.

[1] We discuss the choice of sample below.

Chart 1: International Distribution of Emissions, 2008

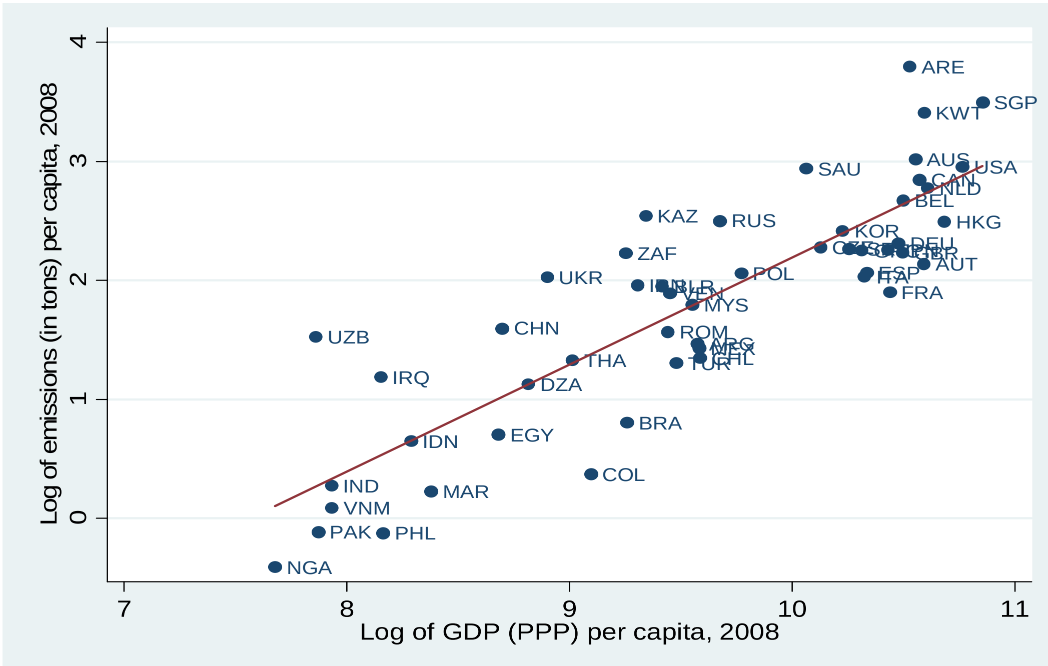
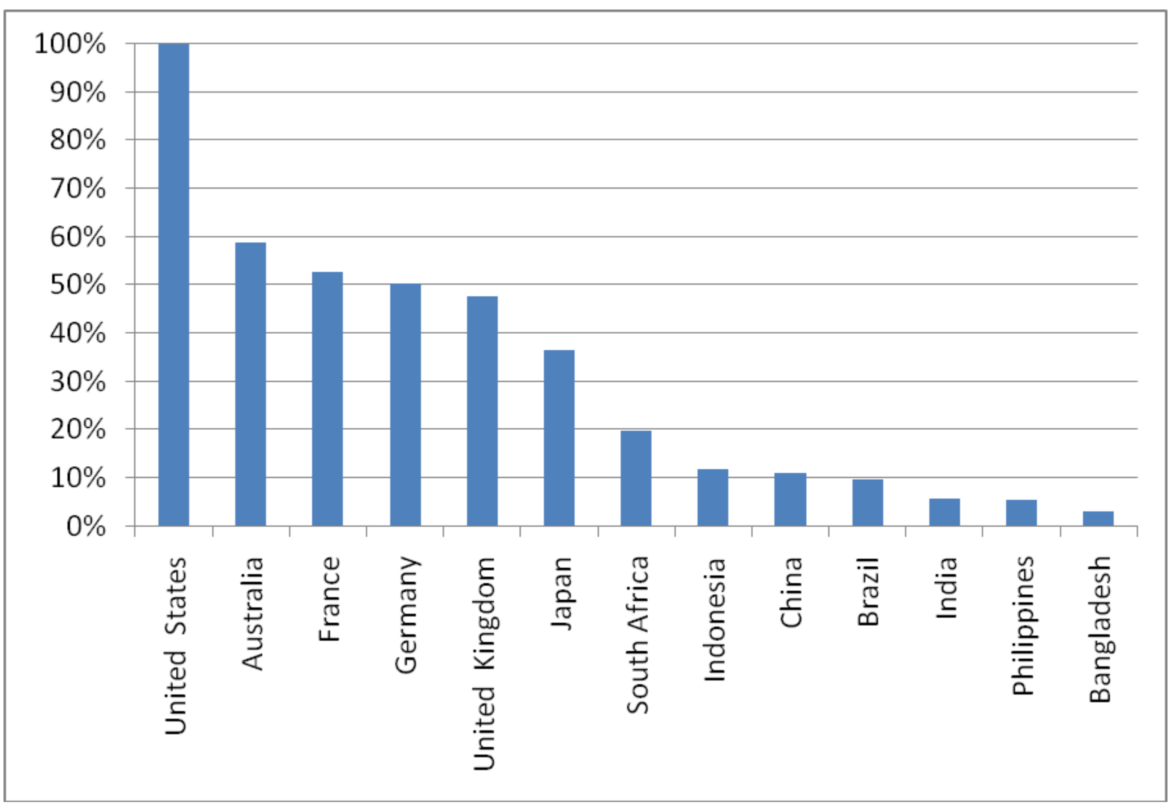


Chart 2. Energy use per capita relative to United States, 2005 (percent)



This paper is organized as follows. Sections II and III spell out the different dimensions of equity, with the former covering the equity principles and the latter highlighting two distinctions, between emissions allocations and cuts, and between starting with the individual versus the country as the unit of analysis. Section IV quantifies the various principles and proposals that emerge from the literature as being important for determining equity, while Section V presents a general framework that encompasses the literature so that specific proposals emerge as special cases. Section VI undertakes a simple quantitative analysis, presenting results for future emissions allocations for a number of specific proposals, and highlighting the consequences of the different principles. In Section VII, we elaborate on the limitations of our analysis as well as ways in which it can be refined and extended. Section VIII offers some concluding remarks.

At the outset, we should clarify a few points about the paper. It will not attempt to discuss the range of important institutional issues in the climate change debate (whether Kyoto should or should not be renewed; what is the appropriate location for future climate financing arrangements; nature of monitoring, reporting, and verification requirements etc). The quantification in this paper is illustrative and deliberately simple. It is not based on sophisticated climate change or economic models where the relationship between principles, unit of analysis and resulting emissions allocations tends to be opaque. Also, the quantitative exercise will be based entirely on emissions of CO_2 rather than all greenhouse gases. In principle, the allocations should cover all greenhouse gases but the focus on CO_2 is a choice dictated by data availability. The paper does not address any issues of science which we take as given by the consensus underlying the UNFCCC process. The paper's focus is a narrow public policy one: to use data and simple quantification to review, encompass, and possibly shed some new light on, the equity debate in the international climate change negotiations.

II. Principles for Determining Equity

Central to our analysis will be the principles for determining emissions allocations. Equity can be based on certain inherent notions of fairness, including concepts of rights, regardless of their consequences. Equity can also be evaluated in terms of the "consequences" of different emissions allocations and typically these consequences relate to economic outcomes or economic welfare of individuals and for nations. The former is the deontological approach while the latter is referred to as the consequentialist (or welfarist) approach (Posner and Weisbach, 2010; Dietz, Hepburn and Stern, 2008).[2]

Our reading suggests that four principles for the equitable allocations of emissions recur in the literature, encompassing both fairness-based or intrinsic criteria as well as consequentialist criteria. We also consider another criterion based on adjustment costs. (Table 1 below lists the various papers that have contributed to the equity literature and highlights the principle or principles advocated in each of them.)

[2] A point on terminology: in the literature, and in this paper, both emissions allocations and emissions rights are used interchangeably. But it should be noted that the conceptual basis of the term "emissions rights" is not uncontroversial. Stern (2009b) argues forcefully that while there can be rights to "goods," for example, enjoying the environmental services of the atmosphere, there is no symmetric right to "bads" such as the right to pollute the global commons. Even if we use the term emissions rights, we do not intend it to connote an ethical right to pollution.

Table 1. Equity principles proposed in the climate change literature

Principles→ *Papers↓*	*Equal per capita emissions*	*Historic responsibility*	*Ability to pay*	*Preserving future development opportunities*	*Adjustment costs*
Agarwal and Narain (1991), Saran (2009), Ghosh (2010)	Y	Y			
Antholis (2009)	N				
Baer et. al. (2007)		Y	Y		
Bhagwati (2009)		Y			
Birdsall and Subramanian (2009)				Y	
Bosetti and Frankel (2009)		Y	Y		
Brazil (1997)		Y			
Cao (2008)		Y	Y		
Chakravarti et. al. (2009)			Y		
Cooper (2008)		Y	Y		
Frankel (2007)	Y	Y?	Y	Y	
GTZ (2004)	Y	Y	Y		
Joshi and Patel (2009)				Y	
Jacoby et. al. (2007)	Y		Y	Y	
Kanitkar et. al. (2010)	Y	Y			
Meyer (2000)	Y				
Muller et. al (2007)		Y			
Pan et. al. (2008)		Y			
Panagariya (2009)		Y			
Parikh and Parikh (2009)	Y	Y			
Posner and Sunnstein (2009); Posner and Weisbach (2010)	N?		Y?		
Spence (2009)			Y		
Stern (2009a) Stern (2009b)		Y	Y		Y?
UNDP (2008)					Y
WBGU (2009)	Y				
Winkler et. al (2006)		Y	Y		Y

Y implies support; N implies opposition; no entry implies neither support nor opposition;? suggests qualification .

1. Equal per capita emissions

The first fairness-based criterion is that regardless of past actions and future opportunities, every citizen of the planet today has an equal right to the atmosphere as a reservoir for absorbing GHG emissions. This criterion is rooted in the idea that all humans are—from the perspective of enjoying the environmental services of the atmosphere—created equal. This has become widely known as the per capita approach because it implies that per capita emissions would be the same across countries.

This principle has been emphasized over the years by a number of developing countries and contributions go back to Agarwal and Narain (1991), Dubash (2009), Saran (2009), and Ghosh (2010). More recently, in the context of carbon budgeting too, the per capita principle is being re-emphasized by the German Advisory Council on Climate change (WBGU, 2009) as well as by Kanitkar et al. (2010). Even others such as Bosetti and Frankel (2009) and Parikh and Parikh (2009), who do not give exclusive status to the equal per capita principle, do consider it relevant in any discussion of equity.

Posner and Weisbach (2010), and Posner and Sunstein (2008), argue that the per capita principle is superficially appealing but in practice is an inefficient way of attaining equity (or redressing inequity) because population and incomes are not (negatively) correlated: that is, giving greater emissions allocations to countries with large populations would not necessarily be the same as giving greater emissions to poor countries. Frankel (2007) implicitly supports the equal per capita principle as the target that all countries would attain in the very long run as their incomes converge.

Although the targets proposed by Stern (2009a) would lead to equal per capita emissions by 2050, Stern (2009b) is ambivalent about the ethical basis of the equal per capita principle. This ambivalence is based in part on the view that while there can be rights to "goods," for example, enjoying the environmental services of the atmosphere, there is no symmetric right to "bads" such as the right to pollute the global commons. It is also based in part on the view that broad ethical claims such as rights to development or participation are more defensible than claims to a narrower set of goods and services.

2. Historic responsibility

A second and perhaps more controversial fairness-based criterion relates future rights to liabilities for past emissions. This notion is based on the fact that the threat of climate change stems from the limited capacity of the atmosphere to absorb certain greenhouse gases. Thus, the atmosphere can be likened to a reservoir. The more GHGs that have been spewed into the atmosphere the more it fills up and the less space there is left for subsequent emissions of gases. The historic responsibility principle suggests that the allocation of future emissions should be inversely related to past emissions. The historic responsibility principle is based on the ethical notion that "thou shalt not harm others" or at least not harm others "knowingly" and that if harm is done there should be compensation. In effect, this is like the polluter pays principle in that historic polluters "pay" by having a lesser claim to future emissions (World Bank, 2010).

This historic responsibility principle also has a long and illustrious pedigree in the climate change negotiations. Among those who have invoked this principle include: Stern (2009b), Winkler et al. (2006), GTZ (2004), Muller et al. (2007), Winkler (2007), Bhagwati (2009a, 2009b), Kanitkar et al. (2010), Pan et al. (2008), Panagariya (2009), Parikh and Parikh (2009), and Dubash (2009). It has been discussed also in Posner and Sunnstein (2008), Posner and Weisbach (2010), Cooper (2008), Joshi and Patel (2009). One of the first contributions to actually elaborate on and quantify the notion of historic responsibility was the proposal made by Brazil to the UNFCCC meetings in 1997 (hereafter Brazil, 1997).

But the notion of historic responsibility has been disputed and the exact manner of giving expression to this notion has also been controversial. An extreme position on historic responsibility is Cooper (2008) who argues that: "… optimal decisions generally require bygones to be ignored. To focus on equity, and thus the alleged retrospective wrongs of the remote past, is to assure inaction."

Posner and Weisbach (2010) argue that a retributive justice perspective on historic responsibility normally requires establishing an injurer who behaved in a "morally culpable" way and establishing the identity of the injured or the victim. In the climate change context, this argument leads to the question whether the perpetrator has to be an individual or a country. If only individuals can be responsible, then according to calculations from the Climate Analysis Indicator Tool (CAIT), only 8 percent of the stock of emissions in 2000 can be traced to the flow of emissions from individuals who are still alive and might be responsible for those emissions (Table 5.1 from Posner and Weisbach (2010)).

Joshi (2010) argues that the notion of historic responsibility is: "…a persuasive claim but it runs up against some powerful moral intuitions. The ACs (advanced countries) did not expropriate knowingly. They acted in the belief, universally held until quite recently, that the atmosphere was an infinite resource. Moreover, the expropriators are mostly dead and gone. Their descendants, even if they could be identified, cannot be held responsible for actions they did not themselves commit."

Bhagwati (2009b) argues that reparations for past harm can be imposed on countries and invokes precedents in US law. He distinguishes between stocks and flows of emissions, arguing that countries should pay for past damage (the stock of emissions). Although he does not argue that past responsibility should determine future emissions allocations per se (which in his view should be determined separately), he nevertheless argues that rich nations should pay compensation for the damage they have caused on account of historic emissions. There is a precedent of such a fund in the US system – the CERCLA (1980), commonly known as the "Superfund", under which a tax is levied on polluting industries and liability established for release of hazardous waste at closed and abandoned waste sites.

Whether corrective justice requires establishment of culpability on the part of the perpetrator is still debated by philosophers. Dietz et al. (2007) note that: "One might also seek to justify emission reductions based on the weaker notion that emitters of greenhouse gases (past, present and future) have obligations – not arising from rights – to consider the climate damage caused, just like a passer-by might be morally obliged to aid someone who has taken ill, even though the ill person is unlikely to have a right to that assistance as such. Barry (1999) constructs a theory of intergenerational justice that he argues does not depend on equal rights across generations. Instead, it depends only on the twin notions of 'responsibility' – that "bad outcomes for which somebody is not responsible provide a prima facie case for compensation" (p97) – and 'vital interests' – namely that there are certain objective requirements that all human beings have, regardless of their location in space or time."[3]

3. Ability to pay

Mitigation will impose economic costs— in terms of reduced consumption and growth because of higher prices of carbon and energy. Most theories of justice would suggest that insofar as costs are imposed, these should be borne more by those whose incomes are greater. In a utilitarian view, with diminishing marginal utilities, world welfare will be maximized—or rather the loss in world welfare will be minimized—if those who are poorer incur lower costs. A Rawlsian perspective would, of course, be even more strongly redistributive. In terms of a carbon budget therefore, most ethical perspectives would require future allocations to be inversely related to the ability (or alternately, capacity) to pay for emissions mitigation. An extreme version of the capacity to pay—in the spirit of Rawls—is captured in the notion of graduation, namely that there will be no burden of payment for countries/individuals below a threshold level of income (Spence, 2009; Chakravarti et al. (2009), Bhagwati (2007b) etc.).[4] This approach is also embedded in the Kyoto Protocol and reflected in the principle of common-but-differentiated responsibilities.

Several contributions to the literature invoke the ability/capacity to pay and /or future opportunities principle, including the GDRs (greenhouse development rights) invoked by Baer et al. (2007), Cao (2009), Frankel (2007), GTZ (2004), Jacoby et al. (2007), and Stern (2009b). Bosetti and Frankel (2009) make emission cuts dependent on how far a country is from a threshold level of income

4. Preserving future development opportunities

The ability to pay principle focuses on adapting to the downside of emissions cuts (i.e. avoiding income losses for those with lowest incomes). But this has a more positive counterpart captured, for example, in the principle of the right to development enshrined in various United Nations initiatives. The right to development is really about preserving the economic opportunities—in this case by allocating sufficient carbon space in the future—for those who are currently poor. A utilitarian perspective is that at the margin an extra unit of emission (and any resulting extra income) will increase world welfare the most if it were allocated to the currently poor whose marginal utility of income is the highest.

The economic opportunities principle is most explicit in Jacoby et al. (2007), who explicitly construct a scenario in which future welfare of countries would not be compromised. Birdsall

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[3] There is also the issue of whether a country's responsibility should apply to the emissions it generates in production or in consumption (see Davis and Caldeira, 2010 and Pan, Philips, and Chen, 2008).

[4] The ability to pay argument has also been articulated in terms of international redistribution. According to Stern (2009b), "Any notions of equality and justice in the allocation of emissions rights should be embedded in a broad view of income distribution..." The point here is that allocations of emissions rights are going to have enormous economic consequences, if not for the distribution of income at least for changes in this distribution. For example, if the carbon budget for the period 2010-2050 is say 750 gigatons, and the average future price of carbon is $50 per ton, climate change going forward will in effect involve distributing nearly 40 trillion dollars. Thus, while some argue that climate change cannot be about addressing global poverty or redressing international income distribution, the magnitudes involved will be large, dwarfing the size of current aid budgets.

and Subramanian (2009) derive emissions allocations under several scenarios each of which preserves the right to economic growth and energy use of developing countries in the future.

5. Adjustment costs

The clearest ethical principles articulated in the literature are equal per capita emissions, (based on the idea that all people are created equal); historic responsibility (based on the idea of doing no harm to others or providing compensation for doing harm); ability to pay (based on basic notions of distributive justice) and preservation of future economic opportunities (based also on notions of distributive justice).

Some would argue that one or more of these four principles should be the only determinants of equitable allocations of emissions. But others have implicitly suggested that adjustment costs should also inform emissions allocations not necessarily because that would be equitable but in recognition of political realities (see Bosetti and Frankel (2009)). Is there an equity rationale for taking account of such adjustment costs?

One of the few contributions to explicitly incorporate adjustment costs is Bosetti and Frankel (2009), who impose several adjustment cost-related constraints on their modeling of emissions reductions. But the proposals in Stern (2007) and in UNDP (2008), which use 1990 as a base for calculating emissions reductions going forward are implicitly “grandfathering” existing emissions allocations, and are in spirit attempting to give weight to adjustment costs by softening the impact of emissions reductions on those who have to make the largest reductions. It is worth noting here that the Stern (2007) and UNDP (2008) proposals are very close in spirit to the “contraction and convergence” ideas first proposed by Meyer (2000), which involves the global carbon budget contracting consistent with climate change goals, with rich countries converging down, and poor countries converging up, to a common emissions per capita target in the long run.

One argument supporting the inclusion of adjustment costs in equity calculations stems from a view that equity should pertain to changes (rather than levels) and that there should be some rough parity in the economic and political pain related to these changes. In a trade context, this is what Bhagwati has called “first-difference reciprocity”: in trade negotiations, countries don’t aim to equalize the level of tariffs but to broadly equalize changes in tariffs and changes in consequential market access. Proponents of including adjustment costs in equity principles for climate change aim to convert the debate from emissions levels (and allocations) to emissions cuts. Adjustments costs are likely to be greater and more compressed in time for countries that have to make larger cuts, which are likely to be countries with large emissions to start with.

The case for reflecting other principles such as the capability to mitigate, measured, for example by the emissions intensity of GDP (GTZ, 2004; Cao, 2009) has even more tenuous links to equity. The argument is that the cleaner a country is, the more difficult it is to mitigate, which should be reflected in emissions allocations. But it is important to distinguish equity from efficiency. While it is certainly true that abatement costs will vary widely across countries, these are not relevant for equity purposes. Abatement action being cheaper in Indonesia than in the United States than in Indonesia is not a reason for allocating more emissions to the latter. With emissions allocated equitably, trading in emissions would ill ensure that efficiency—in the sense of mitigation taking place where abatement costs are lowest—is achieved.

III. Other Dimensions of Equity

But these principles alone are not sufficient to determine emissions allocations. Choices along two other dimensions are necessary to do so: first, whether equity should apply to emissions allocations or emissions cuts? Second, whether the starting point for the analysis should be the individual or the country.

1. Emissions cuts or emissions allocations?

In the literature, the equity principles have been applied in two different ways. They have been applied to the question of fair emissions *cuts* and to the question of fair emissions *allocations*. Contributions that take the former approach include Bosetti and Frankel (2009), Stern (2007), and UNDP (2008) while examples of the latter approach are Jacoby et al. (2007), Kanitkar et al. (2010), Parikh and Parikh (2009), and GTZ (2009). Under the cuts approach it is necessary to clearly define a baseline from which cuts would be measured. This baseline could either be some historic or business-as-usual level. While allocations can in principle be made without reference to a baseline, both approaches should be broadly similar in the sense that allocations imply cuts and vice versa. But in practice they can yield very different outcomes, depending for example on what historical benchmark is chosen and what assumptions, especially on growth rates, are made to project the BAU.

Related to the cuts versus allocations choice is whether the focus should be on flows or cumulative flows. It is well known that the science of climate change involves complex interactions between stocks and flows (Stern, 2008). Emissions flows lead to build-up of stocks and these stocks, with delays and decays, affect temperatures. Going forward, targets for emissions reductions can be formulated as reductions in flows say between two points in time, 1990 and 2050 (Stern, 2007 and UNDP, 2008). Or they can be formulated in terms of cumulative emissions. Insofar as the science places a limit on the total amount of emissions that are consistent with an acceptable increase in temperature, it is more convenient to think in terms of a carbon budget, which is really about cumulative emissions, and about how to allocate this budget (flow targets need to be specified in terms of flow trajectories to respect the overall carbon budget constraint).[5]

2. Equity for whom: Individuals or nations?

A critical dimension of equity is the unit of analysis. International cooperation on climate change takes place between countries and the country has to remain the focus of analysis. Most of the proposals in the literature start with the country as the unit of analysis in discussing equitable emissions allocations (Brazil, 1997; Bhagwati, 2007; India (2010), GTZ (2004); Birdsall and Subramanian (2009); Kanitkar et al., 2010; Parikh and Parikh, 2009; Stern (2007), UNDP (2008). In this paper, we will start with the individual as the building block for any equity consideration is the individual (Cao, 2008; Chakravarti et al 2009; Baer et al.2007). Ultimately, people have rights and countries' rights and obligations derive from individuals (see Stern (2007)). So our analysis will aggregate up from individuals to countries. In Appendix 2, we will

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[5] See the paper by the German Advisory Council on Climate Change (WBGU, 2009) and UNDP (2008) which argue the merits of a carbon budgeting approach.

discuss how this framework can be adapted when the country is the unit of analysis. We show that this is not an easy exercise. We also show that an ad hoc extension of the individual-based approach to a country-level approach yields very different results. The literature on equity in climate change has not recognized the importance of this distinction and therefore not revealed an awareness of its consequences.

The choice of the individual as a unit of analysis is not the same as adopting an “equal per capita principle.” Starting with the individual does, however, allow for the “equal per capita” principle to be one among several principles for allocating emissions. But the inclusion of other principles will typically result in per capita emissions varying across countries, that is, in departing from an equal per capita emissions outcome.

IV. Quantifying Principles and Proposals

Thus far we have defined the principles in broad terms. They need to be applied such that we can derive and quantify every country’s fair share of future emissions allocations. In the context of allocating a given carbon budget, it helps the intuition to do the following thought experiment. Suppose there were one representative individual in each of n countries. We want to ask what the fair allocation of future emissions would be for that individual as a share of emissions for all these individuals. Note that while the objective of the exercise is still to derive fair share of emissions for countries, we begin by thinking of an individual as the ethical unit of analysis and then aggregating to the level of a country.

If the allocation of emissions to a particular country is FE_i, then the share of the representative individual is FE_i / P_i.

A country’s share of emissions in per capita terms is simply its per capita emissions as a share of the sum of per capita emissions in the world. Thinking about the typical person allows the share to be expressed at the level of the country.

Thus:

$$\phi_i^{EQ} = \frac{\frac{FE_i}{P_i}}{\sum \left(\frac{FE_i}{P_i} \right)} \qquad (1)$$

Where ϕ_i^{EQ} defines the fair share of future emissions allocation for country i. The question then turns to specifying/quantifying the principles in a way that is consistent with asking what is the fair share for the typical individual in any given country. We now discuss the principles proposed in the literature.

1. Per capita

The per capita approach simply says that the all citizens of the world should have the same emissions entitlements in the future.

$$\phi_i^P = 1 / k \qquad (2)$$

where k refers to the total number of countries. So, if there were 50 countries, and all had equal per capita emissions, the share of the representative individual would be equal to .02. This would in turn imply that each country's emissions would simply be its share in world population at the relevant point in time, that is, in equal per capita emissions across the world (derived in Appendix 1).

2. Historic responsibility

Since the focus is on each person's future emissions, it would seem appropriate to measure past emissions also in per capita terms. And since historic responsibility relates to cumulative rather than the flow of emissions, the appropriate measure would be per capita cumulative emissions (HE/P) from some point (1990, 1970 or 1850) in the past to the present. And since greater the historic responsibility lower the future share, one way of specifying this principle would be to say that current per capita share is inversely related to the share of cumulative past emissions per capita. The inverse relationship could then be captured as:

$$\phi_i^{HE} = \frac{\dfrac{1}{\left(\dfrac{HE_i}{P_i}\right)}}{\sum \dfrac{1}{\left(\dfrac{HE_i}{P_i}\right)}} \qquad (3)$$

A question that has proved contentious in the debates on equity is: when does history begin for these purposes? Some claim that intent, or to use Eliot's words, "*the awareness Of things ill done and done to others' harm*" is not necessary to use historic emissions as a relevant equity principle (see Helm et. al (2007); Bhagwati (2009); and Cao (2009)). In this view, it would appropriate to measure emissions going as far back as 1850 (the earliest date from which data are available). Others, who would either advocate or concede the necessity of intent would start the clock later. In the climate change context, the culpability argument revolves around timing: when did it become clear (with some degree of scientific certainty) that anthropogenic GHG emissions were a prime suspect in the threat of climate change.[6]

A number of analysts have converged on 1990 as the date after which no government could plead ignorance (Parikh and Parikh (2009); Patel and Joshi (2009)) about the effects of GHGs. It was in 1990 that negotiations that led to the UNFCCC began. However, Kanitkar et al. (2010) argue that 1970 should be the date for assigning responsibility. In their words: "We find that the monitoring of carbon dioxide emissions was fully recognized by the year 1972 in the Stockholm conference on the Human Environment organized by the United Nations . We also note that prior to this conference, in 1968, the problem of global warming due to carbon dioxide emissions had been noted at a conference organized by the American Association for the Advancement of Science, expressly conducted in preparation for the 1972 conference. This further justifies the significance of 1970 as a choice of base year."

[6] Muller et. al. (2008) distinguish strict responsibility from limited responsibility for historic emissions. The former adjust historic emissions for those emissions considered to be harmless (taken to be the level of global ocean sinks). Limited responsibility, invokes Aristotle, who argued that blame could be extenuated by ignorance or circumstances beyond the individual's control.

In our analysis below, we settle on 1970 as the starting point for a more empirical reason. Starting the clock in 1990 seems too recent to count as history and actually penalizes countries that started growing rapidly only since then. In other words, it penalizes those very countries that have suffered from not having had large historic emissions.

3. Ability to pay

Ability to pay for mitigation can be most easily captured in a country's per capita GDP measured in PPP terms.[7] This principle would simply say that a fair share of future per capita emissions should be inversely related to the share of per capita GDP in world per capita GDP.

$$\phi_{\mathrm{i}}^{Y} = \frac{\frac{1}{Y_i}}{\frac{1}{\sum\left(\frac{1}{Y_i}\right)}} \qquad (4)$$

Here Y is a country's per capita GDP measured in PPP terms.

4. Preserving future development opportunities

Future economic opportunities could relate both to energy needs on the consumption side and growth on the production side, taking into account the possibility of technological progress. These are highly correlated so economic growth is perhaps the best indicator for future economic opportunities. Now, future economic growth has typically been predicted based on some view about each country's prospects (as in many projections say by the International Energy Agency (IEA), World Energy Outlook (WEO), Cline (2010)). These are necessarily subjective and typically tend to extrapolate the recent past.

Alternatively, one might simply say that projecting growth over a long horizon should be a more objective supply-side exercise. The simplest rule for doing so is economic convergence, namely, that all countries would tend in the long run to converge to similar standards of living and that future *growth* rates will be inversely related to current *levels* of per capita income. The post-war evidence is that, although not all countries have shown signs of convergence, the major carbon emitters (especially those in Asia) have, which renders the use of current levels of GDP as an appropriate predictor of future growth rates (see Barro and Sala-i-Martin (2003) and Caselli (2005) in particular for evidence on convergence). More recently, in the period (2002-2008) leading up to the recent global financial crisis, the phenomenon of convergence has become more wide-spread with nearly 70 percent of countries growing faster than the United States (Johnson and Subramanian, forthcoming). In any case, it is appealing to use convergence not just as a predictor of future growth but also as a normative basis for preserving the growth opportunities of the poorest countries.

How would one derive a measure of the share of future emissions based on economic opportunities? Future economic growth rates allow future emissions *growth* to be predicted on

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[7] Others have suggested the use of the UNDP's Human Development Index, for example, as a measure of ability to pay (see GTZ, 2004).

the basis of certain assumed rates of technological progress. But we need a measure of the level of future cumulative emissions. For example, China and India are expected to grow at about the same rate in the future but China's cumulative future emissions will be much higher because of its larger initial emissions base. Thus, to get a country's fair share of future emissions based on preserving economic opportunities, we need to combine future economic growth and current levels of emissions.[8]

$$\phi_{\mathrm{i}}^{OPP} = \beta_1 \phi_{\mathrm{i}}^{Y} + \beta_2 \phi_{\mathrm{i}}^{CE} \quad (5)$$

Where ϕ_{i}^{Y} is the inverse share in per capita GDP as in equation (4) and ϕ_{i}^{CE} is the per capita share in current emissions expressed as:

$$\phi_{\mathrm{i}}^{\mathrm{CE}} = \frac{\left(\frac{CE_i}{P_i}\right)}{\Sigma\left(\frac{CE_i}{P_i}\right)} \quad (6)$$

5. Adjustment costs

The reason for incorporating adjustment costs in any discussions of equity is to recognize the importance of, and the constraints imposed by, the status quo in determining future emissions allocations. The greater the distance between current emissions and any long term equitable allocation (for example, given by the equal per capita principle) the greater the likely cuts and hence the greater the adjustment costs. Thus, fair share based on adjustment costs future economic opportunities can be obtained as a combination of the equal per capita principle and (which reflects the long run equitable allocation) and current emissions per capita (a la Frankel (2007)).

$$\phi_{\mathrm{i}}^{ADJ} = \beta_1 \phi_{\mathrm{i}}^{P} + \beta_2 \phi_{\mathrm{i}}^{CE} \quad (7)$$

where EM is current emissions and P is population.

V. Encompassing Framework

We are now ready to bring together all the individual elements on which equitable allocations can be based in one encompassing framework. This is captured in the following general relationship:

$$\phi_{\mathrm{i}}^{\mathrm{EQ}} = f(\phi_{\mathrm{i}}^{\mathrm{P}}, \phi_{\mathrm{i}}^{\mathrm{HE}}, \phi_{\mathrm{i},}^{\mathrm{Y}}, \phi_{\mathrm{i},}^{\mathrm{CE}}) \quad (8)$$

[8] Suppose there were no growth in a country, preserving future economic opportunities would require emissions allocations equal to current emissions every year in the future.

This general formulation can take specific functional forms. For example, the function could be a logarithmic one (as in Cao, 2010 and Baer et al., 2007). There could also be interactions between the variables, for example between the adjustment costs term and the income term, implying that the importance of adjustment costs would depend on a country's level of development.

As an illustrative exercise, we posit for convenience a simple linear functional relationship between the fair share of emissions and its determinants expressed thus:

$$\phi_i^{EQ} = \alpha_1 \phi_i^{P} + \alpha_2 \phi_i^{HE} + \alpha_3 \phi_i^{Y} + \alpha_4 \phi_i^{CE} \qquad (9)$$

Note that the equation has a simple interpretation because the left hand and each of the right hand side variables are expressed as a share. The alphas reflect the weights to be assigned to the different considerations. These weights add up to 1.

The advantage of this framework is that it allows us to represent the different proposals and considerations discussed in the literature as special cases of this more general framework.[9]

<u>$\alpha_2 + \alpha_3 = 1$</u>: Much of the literature (Frankel and Valenti (2009), Stern (2009), Kanitkar et al. (2010), Cao (2009), and Baer et al. (2007)), for example, focuses on taking account of some combination of the income and historic responsibility considerations.

<u>α_1 equal to one:</u> This reflects the long-standing Indian proposal as well as the recent proposal made by the German Advisory Council on Global Change (2009) to achieve equal per capita emission allocations.

<u>α_2 equal to one</u>: This is a variant of the original Brazilian proposal that equitable allocations be determined by historic responsibility alone. There are echoes of this proposal in Bhagwati (2009) who suggests that countries pay reparations on the basis of past emissions. Parikh and Parikh (2009) take this idea one step further by arguing that any taxes levied on historic emissions should be distributed according to population.

<u>α_2 equal to zero</u>: On the other hand, some have argued that the past is irrelevant either because bygones are bygones (Cooper, 2009) or because there is an implicit statute of limitations on responsibility, especially since most of the individuals that contributed to past emissions have long since died (Sunstein and Weisbach, 2010).

<u>α_3 equal to one</u>: This yields the ability-to-pay principle as proposed in Baer et al. (2007) and Cao (2009); in Jacoby et al. (2007), one of the scenarios involves allocating emissions according to the inverse share of per capita GDP. In other words, future emissions allocations would simply take account of, and attempt to, redress the current international distribution of income.

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[9] It is worth noting that this framework is very similar to that used by the International Monetary Fund to determine countries' quota shares and the appropriate principles. Bryant (2010) contains an excellent discussion and review of many of the issues—political and technical—that arise in such an exercise.

$\underline{\alpha_3 + \alpha_4 \text{ equal to one}}$: In principle, this should yield the economic opportunities principle.[10] In one of their scenarios, Jacoby et al. (2007) propose that future allocations be determined so as not to reduce the growth of developing countries.[11] Birdsall and Subramanian (2009), by focusing on future economic opportunities, also accord a weight of one to the income variable.

$\underline{\alpha_1 + \alpha_4 \text{ equal to one:}}$ This yields the 80-20 cuts proposal, advocated by many including Stern (2009) and UNDP (2008), and implicit in the position taken by the United States and EU in their domestic legislative deliberations. The original proposal only specified emissions allocations for industrial and developing countries in the aggregate without also elaborating how these would be allocated amongst these two groups of countries. However, the spirit behind the proposal is explained in Stern (2009), who derives this from a loose application of the equal per capita principle in 2050: that is, there should be convergence in per capita emissions by 2050. [12] In our framework, we are able to generate this outcome for emissions in 2050 by assigning a weight of 0.15 to the per capita principle and a weight of 0.85 to the adjustment costs principle. Implicitly, therefore, this 80-20 cuts proposal can be thought of as giving weight to adjustment costs (which are considered to be greater the larger are current emissions) but moderating that to take account of the need to converge to equal per capita emissions in the future.

VI. Results

We now present results—in terms of the consequences for emissions allocations for countries—for the major proposals in the literature. We first highlight the consequences to major emitters of applying the individual elements identified in equation 9. We then elaborate on the consequences of emissions allocations relative to business-as-usual for five proposals that are closely related to these individual elements.

Our results below are all based on a sample of 50 countries that collectively account for about 94 percent of the world's emissions in 2008 and about 75 percent of the world's population (the list of countries is presented in Appendix Table 1). The sample is based on an emissions threshold--of 0.7 tons per capita—and an income threshold—of $2000 per capita GDP in 2008 and measured in purchasing power parity (PPP) terms--in terms of income. Broadly, we wanted to include the largest current and (potentially) future emitting countries that are likely to be key to achieving successful cooperation.

All our results require that we derive country-level emissions. The process of deriving this for the individual-as-unit approach is described in Appendix 1. We assume, following the German Advisory Council on Global Change, that the total cumulative carbon budget for fossil-based emissions for the period 2010 to 2050 is 750 gigatons, which would ensure a 67% probability of meeting the 2 degrees centigrade guard rail. If we assume that the share of the emissions for the

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[10] The algebra suggests that some combination of current emissions and current per capita GDP (which captures future growth prospects) should capture the economic opportunities principle, but we are unable to precisely obtain the allocation *levels* that correspond to the business-as-usual scenario. We are, however, able to obtain a high correlation (close to 0.95) between allocations using the formula above and the actual business-as-usual allocation.

[11] Strictly, speaking Jacoby et. al. (2007) preserve welfare not growth. When emissions are tradable the former approach leads to somewhat smaller allocations for developing countries but the two approaches should be broadly similar.

[12] This is only a lose application because per capita incomes themselves would not converge by 2050, so why the equal per capita principle should apply at that point rather than at another point is not clear.

countries in our sample, remains broadly unchanged, this would imply a budget for our 50-country sample of 704 gigatons.

Before presenting the results, we would re-emphasize a few points. The quantitative exercise should be seen as illustrative and not definitive and not least because there are many degrees of freedom. For example, the principles that we have discussed can be measured differently (ability to pay can be captured by the UNDP's Human Development index rather than per capita GDP). The measures can be standardized differently (we have standardized by expressing all the variables as shares but these variables could all be expressed as deviations from the mean). We have chosen a linear specification when logarithmic or other functional forms are possible.

1. Impact of principles

It is helpful to begin by spelling out the implications of individual principles before describing the implications of proposals that are based on them. Charts 3A and 3B show the impact of the different principles on total and per capita emissions allocations across countries, respectively.[13] We illustrate this impact by depicting the allocations for each of the principles as the sole basis for determining equitable allocations (i.e. we successively assign weights of one to each of the right hand side variables in equation 9).

Not surprisingly, different principles favor different countries. Countries such as China, India and Indonesia benefit from, and the US and EU are hurt by, the historic responsibility principle. The converse is true when allocations are based on current emissions per capita (because it is this variable that captures adjustment costs and motivates some of the more well-known proposals in the literature). Allocations based on GDP per capita favor the poorest countries such as India and Indonesia (see Chart 3B in particular). It is noteworthy that this principle gives India over two times as much as China in emissions per capita, reflecting China's higher income level. Similarly, India receives about three-and-a-half times emissions per capita as Brazil under the ability-to-pay principle because of the corresponding income differentials (Chart 3B), and this translates into even larger differences in total emissions because India's population is about six times greater (Chart 3A).

Per capita allocations are very similar under the historic emissions and ability-to-pay principles. It is also noteworthy that both historic emissions and ability-to-pay principles yield greater per capita allocations than under the equal per capita emissions principle for countries such as India and Indonesia. For China and Brazil the converse is true. This shows that as long as countries are far away from converging to common levels of economic development, the poorer countries may be better off embracing principles other than the equal per capita principle.

[13] The Charts in Appendix 2 show the impact of the different principles on the emissions allocations under the country-level approach.

Chart 3A. Cumulative Emissions Allocations, 2010-2050 (gigatons)

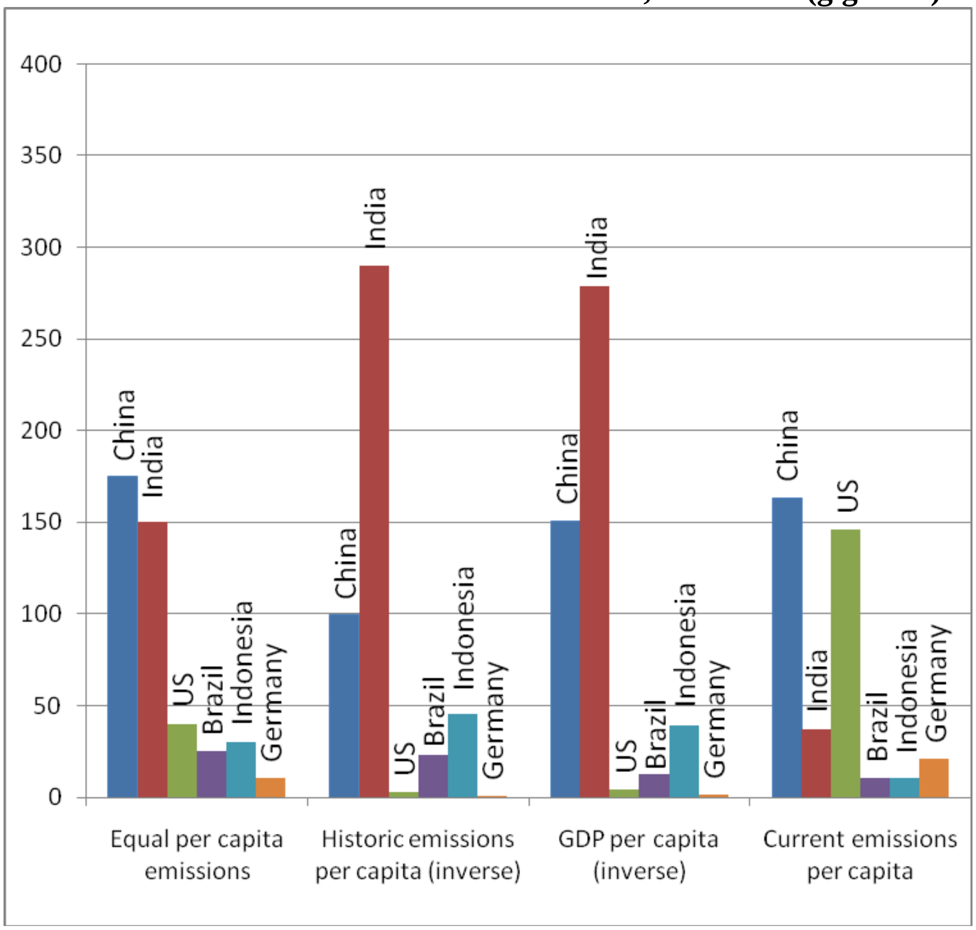
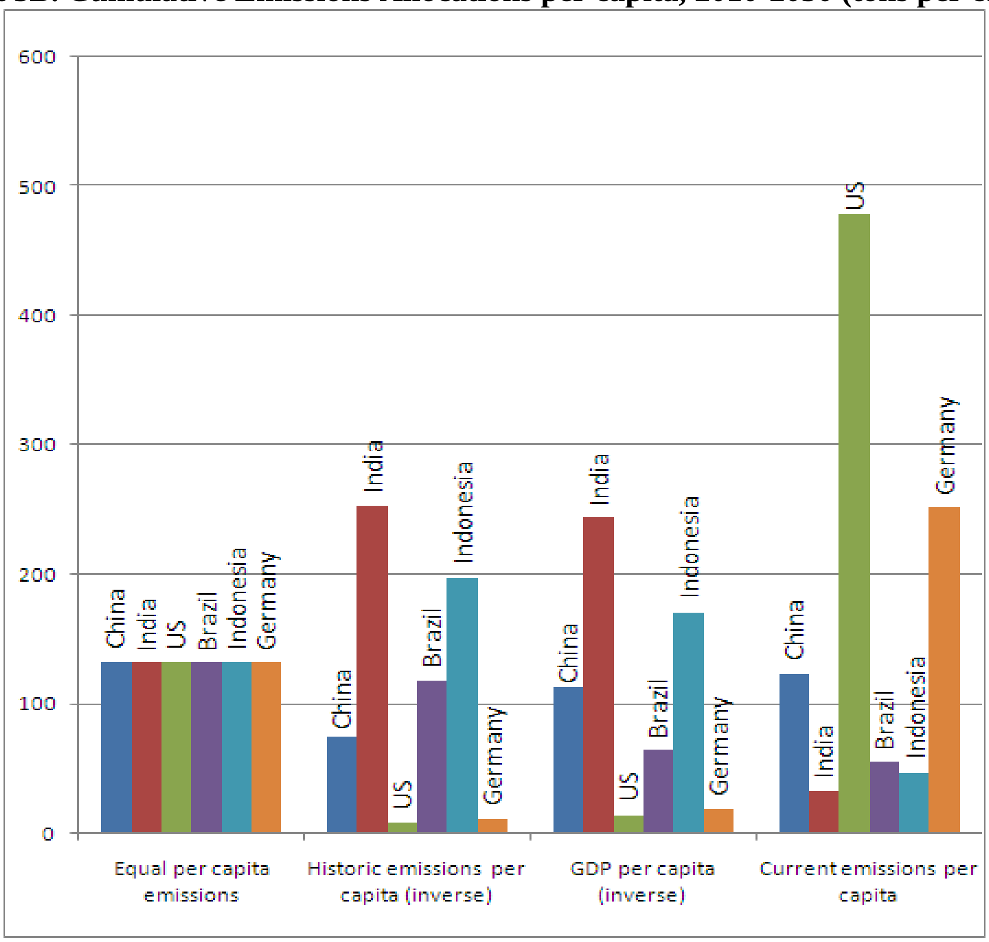


Chart 3B. Cumulative Emissions Allocations per capita, 2010-2050 (tons per capita)



Note: With one exception, both charts show allocations for the major countries if each of the principles were the sole basis for allocations (i.e. as if the alphas in equation 9 were set to one.

We show the correlation between the individual elements in Appendix 3 which provides a clue to what might happen if these individual elements were to be combined, as they are in some of the proposals in the literature. There is a high degree of correlation (0.85) between per capita GDP and historic responsibility. This suggests that these two variables might be capturing similar notions, which we discuss below, and that these principles will tend to re-inforce each other. But there is also a fairly high negative correlation between these two principles, on the one hand, and the adjustment costs principle on the other so that the latter will work in the opposite direction.

2. Impact on countries relative to business-as-usual

Thus far, we have compared the individual principles in terms of their implied emissions allocations for different countries. But countries will also be concerned with the impact of different proposals relative to business-as-usual. In Charts 4A –4E and Tables 2-4 below, we compare the impact of each of five proposals—equal per capita emissions, historic responsibility, ability to pay, 80-20 cuts, and preservation of future economic opportunities—on different countries. Specifically, we compute the difference in the annual average emissions growth rate between each of the scenarios and the emissions growth rate under the business-as-usual scenario and plot this difference against the per capita GDP of countries.

We obtain emissions growth in BAU from Birdsall and Subramanian (2009), which is optimistic about technology creation and dissemination in the business-as-usual situation. These technology assumptions are combined with those about population and per capita GDP to derive BAU emissions growth.[14]

We specify the preservation of future economic opportunities principle in the following manner: we give all countries that have a per capita GDP (PPP) in 2008 of less than US$20,000 their business-as-usual allocations. This captures the graduation notion that people below certain thresholds should not have to suffer any consequences (as in Bosetti and Frankel (2009)). For countries above this threshold, we reduce their emissions allocations proportional to their business-as-usual levels so that the global carbon budget is respected.

Several features stand out in these charts and tables. First, most proposals are broadly equitable in that they inflict smaller emissions growth cuts on poorer countries (reflected in the significantly negative relationship with current GDP per capita in the charts). The exception is the 80-20 cuts proposal (Chart 4D) which has a strong status quo bias. In fact, this feature is common to some of the most influential contributions to the literature which have focused on emissions cuts rather than allocations (Stern, 2007; UNDP, 2008; Bossetti and Frankel (2009); the Jacoby et al. (2007).[15] In Stern (2007) and UNDP (2008) which advocate the 80-20 cuts proposal and in the Jacoby proposal for 70-30 cuts, the baseline is 1990 emission levels.

When the benchmark is some historical level of emissions, a cuts approach tends to favor the status quo and hence preserves current inequities. Consider for example the 80-20 cuts proposal of Stern and the UNDP. At first blush, an 80 per cent reduction by the industrial countries and a 20 per cent reduction by developing countries relative to their 1990 emission levels, appears strongly progressive. However, its real implications for equity are shown in Panel D below. This inequity also becomes apparent when we translate the cuts into emissions allocations for

[14] The per capita growth assumptions for all countries for the period 2010-2050 are based on convergence (Appendix Table 1).

[15] Kanitkar et. al. (2010) combine cuts with allocations.

individual countries. In fact, this allocation can be generated in our encompassing framework (equation 9 above) with a weight on the adjustment cost principle of 0.85 and a weight of 0.15 on the equal per capita principle.

A second feature that is illustrated in these charts and Table 2 is that a few large and poor countries—India, Indonesia, the Philippines, Nigeria, Vietnam, and Pakistan—tend to receive consistently high allocations. Any allocation that starts from the individual as a unit of analysis and then aggregates to the level of countries on the basis of population naturally favors large countries which are on average poorer.[16] China, in contrast, experiences cuts in nearly all scenarios because its per capita income is higher.

It is possible to construct a summary measure of the overall impact on emissions growth of the different proposals, taking account of a country's size and income level (Table 3). The rationale here is that we want to give larger weight to countries that are large and poor. As expected, the 80-20 cuts proposal stands out: the average reduction in emissions growth relative to BAU under this proposal is -2.25 percent which is almost as large as the emissions growth in the BAU scenario. The ability-to-pay principle generates the least average reductions in emissions growth.[17] The other three proposals produce roughly similar results.

It is worth highlighting that most proposals involve reductions in emissions growth for nearly all countries (see first row in Table 3). The exception is the proposal to preserve future economic opportunities, which by construction, insulates 29 low income countries from emissions cuts. But this only transfers the burden of emissions reductions to high-income countries each of which suffers a reduction in emissions growth of close to 20 percentage points. Translated into levels of emissions, this implies that the United States must cut emissions by 125 percent: put differently, over the next 40 years it would have to add to the atmosphere's capacity as a carbon sink rather than to deplete it or to finance larger cuts elsewhere.

One point that deserves emphasis relates to the BAU and the related preservation of future economic opportunities proposals. Business-as-usual emissions levels are closely related to future economic growth, which is based on some view about each country's prospects. Alternative growth projections have profound consequences for emissions allocations (for example, in the projections by EIA (2009), growth is assumed to be 4.9 percent and 3.9 percent, respectively for China and India. In contrast, the Birdsall and Subramanian (2009) projections for the two countries, based on assuming convergence, are 4.1 percent and 5.2 percent, respectively. Convergence has some empirical basis but it also has normative appeal in leaving room for higher potential growth for those who are currently poorer.

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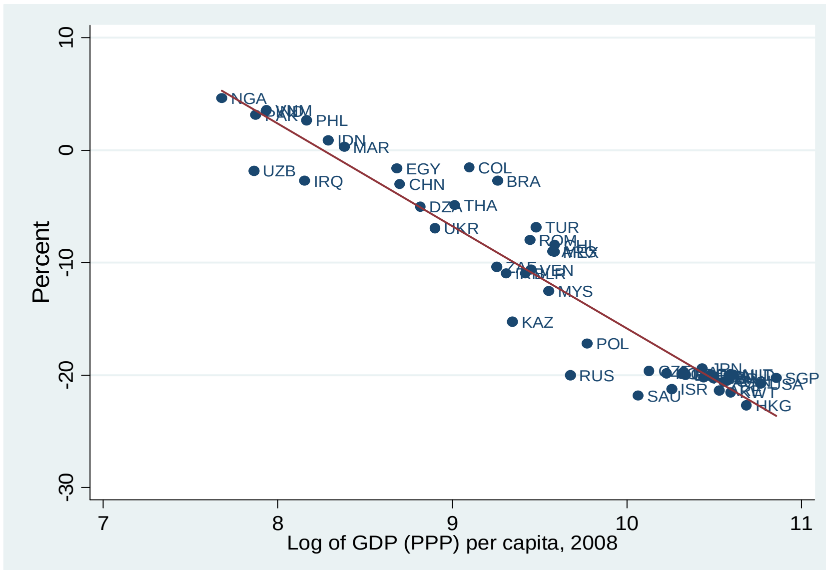
[16] In Appendix 2 we show that if we were to apply the same principles directly at the country level, the resulting allocations would not be so equitable because in our sample large countries are on average poorer.

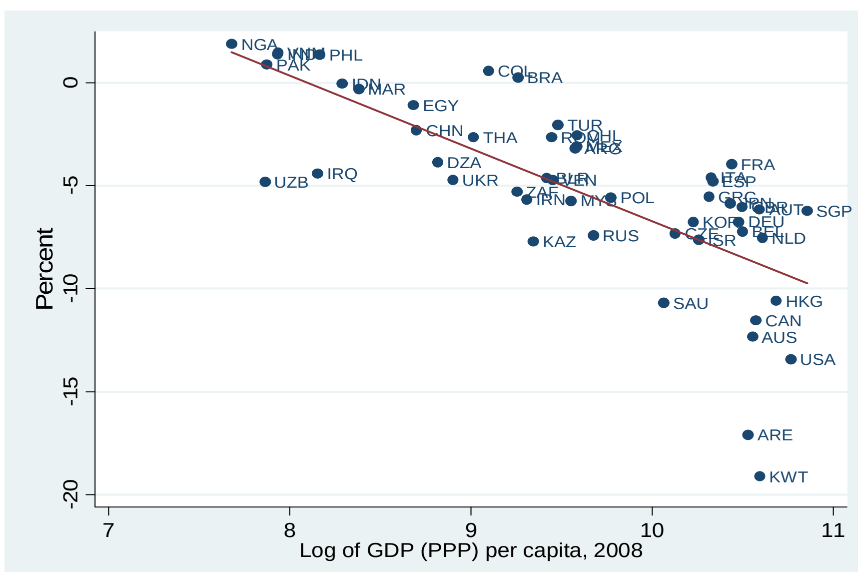
[17] This outcome is in part a consequence of how our summary measure is constructed. This measure attaches a higher weight to the emissions growth of poorer countries, who are the beneficiaries of more generous allocations under the ability-to-pay principle.

Chart 4. Implications of Alternative Proposals: Change in emissions growth compared to business-as-usual (annual average % between 2010 and 2050)

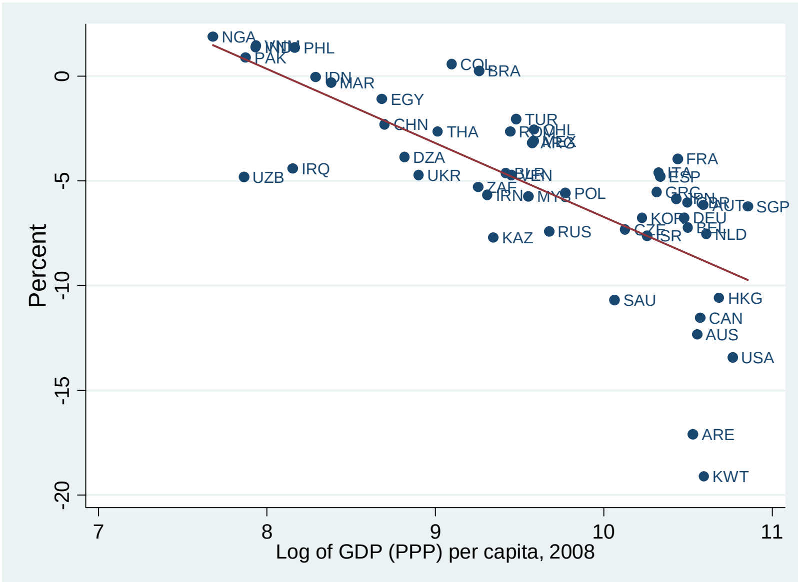
A. Equal per capita emissions



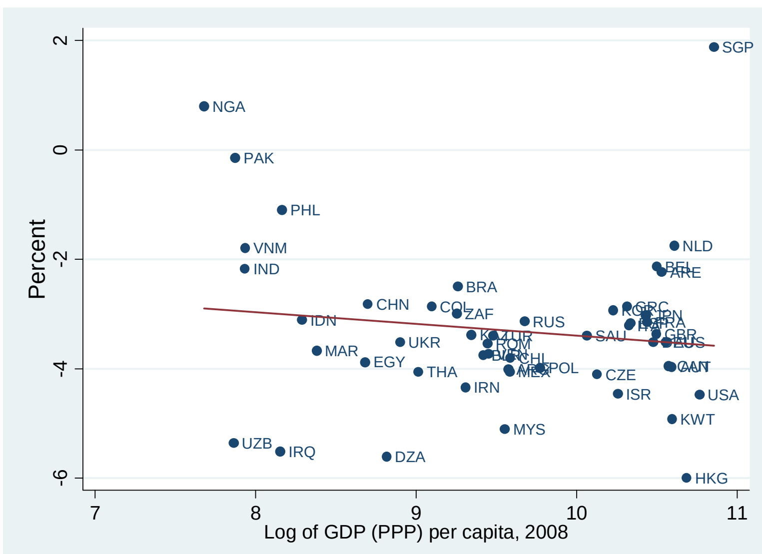
B. Historic responsibility



C. Ability-to-pay (based on per capita GDP)



D. **80-20 Cuts**



E. Preserving future development opportunities

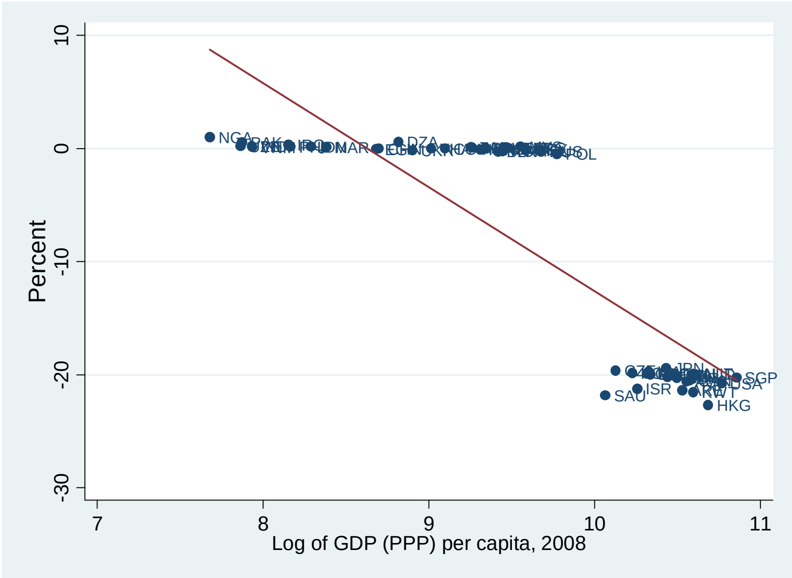


Table 2. Countries least adversely affected under different proposals 1/

Equal per capita emissions	Historic Responsibility	Ability to pay	80-20 Cuts	Preserving future development opportunities
India	India	India	Singapore	China
Indonesia	Indonesia	Indonesia	Pakistan	Russia
Brazil	Brazil	Pakistan	Nigeria	India
Pakistan	Pakistan	Nigeria		Iran
Nigeria	Nigeria	Vietnam		South Africa
Vietnam	Vietnam	Philippines		Mexico
Philippines	Philippines	Morocco		Indonesia
Colombia				Brazil
Morocco				Ukraine
				Poland
				Turkey
				Thailand
				Kazakhstan
				Venezuela
				Argentina
				Egypt
				Malaysia
				Pakistan
				Uzbekistan
				Algeria
				Romania
				Iraq
				Nigeria
				Vietnam
				Philippines
				Belarus
				Colombia
				Chile
				Morocco

1/ A country appears on the list if the difference between its emissions growth in each of the scenarios and that in the BAU scenario is greater than - 0.5 percent.

Table 3. Emissions impact under alternative scenarios consistent with meeting climate change goals

	Equal per capita emissions	Historic Responsibility	Ability to pay	80-20 Cuts	Preserving future development opportunities
Number of countries whose emissions growth does not fall short of BAU growth rate by more than 0.5 percent emissions growth -0.5%)	0	7	7	3	29
Sample of countries	50	50	50	50	50
Annual average emissions growth in business-as-usual (population and per capita GDP weighted)	2.60%	2.60%	2.60%	2.60%	2.60%
Difference with emissions growth in business-as-usual (population and per capita GDP weighted) 1/	-0.28%	-0.33%	0.17%	-2.25%	-0.32%

1/ Annual average growth rate between 2010 and 2050; calculated as $\frac{\sum \phi_i^p \phi_i^y \left(\dot{e}_i - \dot{e}_i^{BAU} \right)}{\sum \phi_i^p \phi_i^y}$ where ϕ_i^p is a country's population share; ϕ_i^y is a country's share in inverse per capita GDP; $\dot{e}_i$ is the annual average emissions growth between 2010 and 2050 in each of the scenarios; and $\dot{e}_i^{BAU}$ is the annual average emissions growth between 2010 and 2050 in the business-as-usual scenario.

Table 4. Cumulative emissions under alternative scenarios and proposals for major emitters, 2010-2050 (gigatons)

	Proposals in this paper						Other proposals			
Proposal → *Country ↓*	Business-as-usual	Equal per capita emissions	Historic Responsibility	Ability to pay	80-20 Cuts	Preserving future development opportunities	German Advisory Council (2009) 1/	Kanitkar et. al. (2010) 2/	Bossetti and Frankel (2009)	Jacoby et. al. (2007) 3/
China	295.2	174.8	99.2	150.5	162.2	295.2	148.0	262.0	299.1	181.4
USA	283.3	40.1	2.5	4.4	133.7	-67.9	35.0	67.5	212.2	78
Russia	65.8	18.7	1.5	6.1	40.1	65.8	15.0	22.3		
India*	108.1	150.4	289.7	278.5	57.9	108.1	133.0	210.0	78.6	99.8
Japan	43.2	16.8	2.1	2.6	28.0	-10.4	14.0	16.2		15
Germany	33.3	10.8	1.0	1.6	19.1	-8.0	9.0			
Canada	25.3	4.4	0.3	0.6	13.2	-6.1		7.9		8
Indonesia	31.8	30.0	45.1	38.9	13.2	31.8	25.0	47.7		31.0
Brazil	24.2	25.3	22.8	12.4	10.9	24.2	21.0	29.6		
EU**	148.5	56.5	7.6	10.1	86.1	-12.8	54.0	52.7	153.0	49.5
All countries in sample	1413.6	704.0	704.0	704.0	704.0	704.0	750.0	1440.0	1220.6	1011.1

1/ From Table 5.3-2 of the paper
2/ From Table 11 of the paper
3/ Corresponds to their full compensation, equal allocation scanario

Finally, the implications of some of the other proposals in the literature, shown in the last 3 columns of Table 4, are worth noting. First, none of them generates outcomes that are consistent with meeting the 2 degrees centigrade guardrail objective which requires respecting the carbon budget of 704 gigatons for the period 2010-2050. Bosetti and Frankel (2009) devote attention to adjustment costs and also incorporate graduation criteria for emissions cuts, which leads to several developing countries, but not China, following their business-as-usual trajectories until the middle of this century. This proposal is closest in spirit to our preservation of economic opportunities allocation. However, in accommodating these different constraints, they exceed the carbon budget. The Jacoby et al. (2007) proposal is interesting because it respects the criterion of developing countries not losing in welfare terms relative to business-as-usual. But that too does not meet safe climate change goals.

A different way of noting the difficulty of attaining both climate change and developing country growth and energy goals is to compare the allocations under BAU, shown in column 1, and those in column 6 (preserving future economic opportunities). If countries with a per capita GDP of less than US$ 20,000 were to follow their business-as-usual trajectory, their carbon budget alone would be about 870 gigatons, requiring high income countries having to reduce their cumulative emissions drastically from about 540 gigatons (in their business-as-usual trajectories) to – 170 gigatons to meet the global carbon budget.

VII. Caveats and Extensions

1. Climate adaptation

Our framework for allocating emissions rights does not take into account the costs of adaptation to climate change, even though some have argued that these costs be considered in any cooperative agreement (see e.g. Indian submission at http://unfccc.int/meetings/ad_hoc_working_groups/lca/items/4578.php). How these costs should influence equitable allocations is not straightforward. On the one hand, if a country would incur significant costs of adaptation to climate change, equity considerations might dictate a larger allocation of emissions to it in order to compensate for the loss in welfare. Since poorer countries and those closer to the equator are more likely to be affected (see Cline (2007), and World Bank 2010), it would be reasonable to use these criteria to reflect fairness for equitable adaptation calculations. On the other hand, such a country also derives a greater benefit from, and therefore has a greater stake in, preventing climate change and therefore could be required to make a greater contribution by way of emission cuts. It is not clear how a balance must be struck between these conflicting considerations.

2. Graduation at the country level

Several contributors to the literature, including Bhagwati, Spence (2009), and Frankel and Valenti (2009) have suggested that only countries above a certain threshold level of development (usually defined in per capita GDP (PPP) terms or based on some human development type of index) be required to take on emissions cuts and thus contribute to burden sharing. Implicitly, this approach is akin to allowing countries below this threshold to proceed along their business-as-usual emissions paths. In our framework, this is taken into account by using income as a criterion of emissions allocation so that the poorest countries, which are likely to grow faster in the future, receive larger emissions allocations. The graduation criterion can also be applied at the individual level, which we discuss below.

3. Intra-national and inter-national equity

Our unit of analysis is the representative individual within a country. Clearly, there is large inequality within countries as there is across countries, so the assumption that one average-income earning individual represents the country is not strictly valid. Can our framework allow for the incorporation of this inequality within countries? Suppose, for analytical simplicity, there were two types of individuals--rich and poor--within all countries. Suppose too that we defined rich and poor according to a threshold (akin to a graduation criterion) which dictated that the rich individuals would not need any space in terms of future growth opportunities by virtue of already being rich. This would imply that for the rich individuals, in equation 7 above the coefficient on the per capita GDP term would be zero: that is, income would not be a criterion in determining fair emissions allocations, because the rich across the world did not need any special treatment. For poor individuals, however, current income would remain a criterion in determining fair allocations. So, if we added all the rich and poor individuals within a country to arrive at a country level allocation of emissions, the coefficient on the income term would be weighted by the proportion of poor within any given country.

It may be helpful to contrast our approach with that of Cao (2008) and Baer, Athanasiou and

Kartha (2007) and Chakravarty et al. who also incorporate intra-national inequality but in a slightly different manner. In their approach, the question is not the fair allocation of emissions (a benefit) but the fair allocation of burden sharing (a cost). Since they posit that burdens should only be shared by individuals above a certain income threshold (defined across all countries), they focus on measuring the rich within a country and treating this as the unit over which equity criteria should be applied. Our approach would instead focus on the poor within every country and ask how much extra allowance must be made when applying the criterion of ability to pay in order to arrive at country-level emissions.

4. Emissions allocations and technological change

Does it matter for the simulations above if actual technological progress turns out to be faster than expected? Most of the simulations above yield shares of the total cumulative emissions budget for a country starting with the representative individual in it as the unit of analysis. These shares are calculated independently of any assumptions about the pace of technological progress. If emissions per unit of economic activity decline faster than expected, then for each country a higher level of economic activity is consistent with any given emissions allocation. In other words, there is no reason that faster-than-expected technological progress should change the equitable allocation of emissions.

The one exception is the principle where developing countries receive an emissions allocation that enables them to achieve business-as-usual growth rates. Here the emissions allocation is necessarily based on certain assumptions about the pace of technological progress which determines how the relationship between emissions and economic activity evolves. Faster than expected technological progress enables developing countries to achieve business-as-usual growth with lower emissions than their initial allocations. The surplus emissions could then be reallocated among countries which received more stringent initial allocations.

5. Horizon

Our simulations have allocated cumulative emissions over the next forty years on the basis of attributes, such as per capita income, observed today. But this may be politically difficult because it may be neither feasible nor desirable to conclude binding agreements over such a long horizon especially if the underlying attributes of participants change significantly. Thus, it may be difficult to tie the hands of governments indefinitely into the future.

An alternative would be to determine targets over a shorter period with no agreement today about what would happen beyond. The Kyoto Protocol with its in-built expiration date had this flavor. As noted above, our approach can be adapted to alternative time frames. The problem with this latter course, of course, is the lack of certainty for market players who need to plan over longer horizons.

The key choice is to define allocations over a time period that is long enough to create a stable environment for public and private decisions but not so long that the underlying criteria for making allocations become irrelevant. A period of ten years has been suggested as reasonable (Frankel, 2007). The question then would be whether any current agreement would pertain only to the level of allocations over the next 10 years, or also include the rules that would guide future allocations based on changing circumstances. These rules could cover only the variables on the basis of which future allocations would be made or also specify how the weights attached to these variables would evolve. For example, it could be agreed that the weight attached to the "adjustment cost" term or the historic emissions term would decline in future time periods. Our framework has the flexibility to allow for all these possibilities.

6. Forests

Do forests deserve special attention in an equity framework? Tropical forests are under pressure because of the economic incentives to chop them and derive economic value from the resulting timber and from the land that becomes available by the clearing of forests. Thus, emissions mitigation to the extent that it involves preserving forests might lead to the loss of economic opportunities that could be derived from clearing them.[18] The question is whether forests should be part of the general carbon budgeting exercise in the future or whether they should be treated sui generis, for example, through financial flows. The argument for the latter might simply be that very few countries have a large stake in the forestry issue. Moreover, this sui generis treatment seems to be the drift in international discussions, reflected, for example, in the United Nations' initiative for Reducing Emissions from Deforestation and Forest Degradation (REDD).

VIII. Concluding Remarks and Possible Way Forward

Even as the world contemplates stronger action to reduce CO_2 emissions to prevent catastrophic climate change, how this goal can be accomplished equitably has become central to the debate. This paper has presented an analytical framework to encompass the existing contributions to the literature on equity in climate change. It seeks, in particular, to highlight the consequences—in terms of future emissions allocations—of different approaches to equity.

It seems that there is a shared recognition that the status quo in terms of emissions allocations is unbalanced. Today, rich countries have substantially greater per capita CO_2 emissions—reflecting substantially higher usage of energy per capita—than poor countries. There is less agreement on how equity considerations should inform future action on climate change, reflected in the different proposals that have been made.

Four equity-based principles and related proposals recur in the literature. These suggest that emissions allocations be: (i) allocated equally on a per capita basis; (ii) inversely related to historic responsibility for emissions; (iii) inversely related to ability to pay; and (iv) directly related to future economic opportunities. The case has also been made for taking account of adjustment costs in emissions allocations.

[18] Some authors such as Frankel (2007) and Cao (2009) have suggested that hydrocarbon endowments should be a factor in equity determinations. The argument presumably is that emissions mitigation, by reducing the price of carbon will result in a decline in the wealth of countries with large hydrocarbon endowments which should be compensated. It is difficult to see why countries with large incomes such as Saudi Arabia or the United Arab Emirates even with their endowments of hydrocarbons would merit compensation. Insofar as hydrocarbon endowments deserve inclusion in the equity calculus, it is more likely to be appropriate for poorer countries such as Nigeria and Angola.

At first blush, each of the principles discussed above seems to merit inclusion in any determination of equitable emissions allocations. Thus, privileging any one principle (equal per capita) or a sub-set of principles (equal per capita and historic responsibility) to the exclusion of others does not seem justified. But the conclusion—perhaps obvious—seems to be that there may be reason to favor just one principle: the preservation of future economic opportunities. Why?

The adjustment costs principle taken in isolation, which motivates formulating equity in terms of emissions cuts, tends to favor the status quo. Even reasonably progressive cuts relative to historic levels--for example the 80-20 cuts proposal that implicitly accords primacy to adjustment costs--tend to favor large current emitters such as the United States, Canada, Australia, the oil exporters and China, at the expense of the emissions frugal. Cuts relative to business-as-usual tend to favor countries whose growth forecasts are greatest, particularly China, when forecasts are based on recent economic performance.

Other principles of equal per capita emissions, historic responsibility and ability to pay favor some large and poor developing countries such as India, Indonesia, the Philippines, Pakistan and Nigeria. In any purely equity-based approach going forward, these countries would not be required to assume onerous mitigation commitments.

However, these equity principles would hurt not just industrial countries but other developing countries. Thus, a weakness of these proposals is that they would inflict unjustified economic costs on some poor countries that do not receive emissions allocations needed to sustain growth. At the same time, the generous allocations provided to the large and poor countries in excess of their growth needs would amount to unjustified largesse because then climate change would become an instrument for redressing unrelated inequities.

A weakness of these proposals is that they would, on the one hand, inflict unjustified economic costs on a large number of poor countries that would not receive emissions allocations needed to sustain likely growth rates. On the other hand, the proposals would provide allocations to some countries in excess of their growth needs, which could be seen as unjustified largesse because then climate change would become an instrument for redressing unrelated inequalities.

The principle of "preserving future development opportunities" is most appealing because it corresponds closest to the notion that developing countries should not be constrained in the future by a problem that they did not largely cause in the past. The climate change problem has imposed a hard "carbon budget" constraint on humanity. In the absence of climate change, there would not have been such a constraint. The key equity question is whether this hard budget constraint should bite for developing countries in the sense of curtailing their future economic opportunities (growth and energy needs). And the answer seems to be that it should not: not just because they are poor but also because they did not cause much of the problem.[19]

[19] It is worth noting that the historic responsibility matters only to the extent that future opportunities for developing countries are foreclosed. Developing countries cannot ask to be compensated for the damage to their future opportunities and also for historic responsibility (assuming, of course, that the motivation behind historic-responsibility compensation is damage caused, not pure retribution or revenge), because that would be double-counting.

If we assume that incomes of different countries tend to converge over time, which has both some empirical support and normative appeal, then developing countries have the greatest economic opportunities. Preserving these opportunities would require emissions allocations to all developing countries close to their projected business-as-usual levels. As a result, this principle minimizes conflicts within developing countries. It also has the virtue of not making climate change an instrument for income redistribution for reasons unrelated to climate change. However, the burden of meeting climate change goals would then fall entirely on industrial countries which would be obliged to make drastic cuts in emissions, especially if China's large business-as-usual emissions have to be accommodated. The resulting economic contraction of industrial countries would in turn have negative feedback effects on developing countries via the trade and finance channels.

Hence, one key and broad point that emerges from this review is that conflicts of interest are both inherent and strong—perhaps irreconcilably so—in discussions of equity in emissions allocations. They are inherent because the exercise is about allocating a fixed aggregate carbon budget. They are strong because the budget is not really fixed but shrinking dramatically relative to the growing needs of developing countries. Science demands drastic compression in aggregate emissions in order to keep temperatures below reasonable levels with reasonable probability. Given current rates of technological progress, the available carbon budget is not even adequate to sustain business-as-usual growth rates for developing countries, let alone for the world as a whole. The required cuts would only be small enough to be politically acceptable if there were radical—historically unprecedented—technological breakthroughs that allowed significantly higher levels of growth and energy consumption for given levels of emissions.

It may, therefore, be desirable to shift the emphasis of international cooperation toward generating a low-carbon technology revolution; equity would have a key but different role in shaping such international cooperation.[20] Equity would be less about mediating the allocation of a fixed emissions pie than about informing the contributions of different countries in generating a low-carbon technology revolution so as to enlarge this pie. Such a revolution can transform climate change into a non-zero sum game, offering perhaps the only hope of reconciling the development needs of low-income countries with the climate change goals of humanity.

[20] It is an open question as to whether cooperation on generating technological progress should follow the current paradigm of establishing targets and timetables as part of one grand agreement, or involve a variety of loosely coordinated smaller scale agreements each one of which addresses a different aspect of the challenge (Barrett and Toman, 2010).

Appendix 1: Deriving Country-Level Emissions from Fair Per Capita Emissions Share[21]

Equation 7 in the text provides a formula for estimating the fair per capita emissions share for a country. But we need to derive total emissions for a country. How do we do so?

Recall that the formula for fair per capita emissions share is:

$$\phi_i^{EQ} = \frac{\frac{FE_i}{P_i}}{\sum\left(\frac{FE_i}{P_i}\right)} \qquad (1)$$

We need to derive an expression for FE_i

The overall carbon budget for 2010-2050 (which we set at 704 gigatons for the 50 countries in our sample) is simply the population times the per capita emissions for each country summed over all countries, which can be expressed as:

$$\sum P_i \frac{FE_i}{P_i} = Available\ \ carbon\ \ budget\ \ for\ 2010-2050 = 704 \qquad (2)$$

Re-writing (1) we get:

$$\frac{FE_i}{P_i} = \phi_i^{EQ} \times \sum\left(\frac{FE_i}{P_i}\right)$$

$$= \phi_i^{EQ} \times C$$

$$\sum P_i \phi_i^{EQ} C = 705$$

$$C = \frac{705}{\sum P_i \phi_i^{EQ}}$$

This yields the following expression for each country's total emissions as a function of variables

[21] We are grateful to Olivier Jeanne for helping us with the derivations below.

that we observe and estimate.

$$FE_i = P_i \phi_i^{EQ} \quad \times \frac{705}{\sum P_i \phi_i^{EQ}}$$

If ϕ_i^{EQ} is a constant as in equation 2 in the text, then the preceding expression reduces too:

$$FE_i \,/\, P_i = \frac{705}{\sum P_i}$$

which implies equal per capita allocations across the world.

Appendix 2: Impact of the Equity Principles Under Country Level Approach

Recall that in Section IV, we derived the fair emissions share for countries by starting with individuals and aggregating up to the level of countries. Because of treating individuals as the unit, our criteria for equity (the various right hand side variables in equation 9) were also specified for the representative individual. What if we started instead by asking directly what should determine a country's fair share of emissions?

The first difficulty we encounter is how to specify or scale the variables that capture the equity principles. For example, in the case of the ability to pay principle, should the variable be specified as per capita GDP or aggregate GDP? Is a country as rich as its average citizen (suggesting a per capita specification) or is it as rich as its total output (suggesting an aggregate specification)? Even though the former criterion has some appeal, its choice would ignore the size of a country and lead to two countries—say Singapore and the United States—receiving the same emissions allocations despite their vastly different populations. The latter would respect scale but could lead to two countries that have similar aggregate GDPs—Indonesia and Belgium—receiving the same emissions despite their vastly different levels of development.

Similarly, should historic emissions, hydrocarbon endowments or current emissions (which affects adjustment costs) be scaled by population or not? Nevertheless, to illustrate the consequences of the country-as-unit as opposed to individual-as-unit we extend the framework in equation 9 with the only difference that the basic equity question—the left hand side of the equation—is what a country's fair share of emissions should be. In this case, a country's fair share of emissions would be:

$$\phi_i^{EQC} = \frac{FE_i}{\sum FE_i}$$

where now FE_i is a country's total emissions and $\sum FE_i$ is world emissions and the extra C superscript denotes the fact that we are now referring to country level emissions. Note the difference with the comparable specification at the individual which is expressed in equation 1. For purposes of comparison, we continue to express all the right hand side variables in per capita terms. We illustrate below the consequences of this change. First, in the charts below, we show the impact on emissions allocations of the four elements when applied at the country level (comparable to Charts 3A and 3B in the text). Allocations do not change for the population variable. But for all the other variables there are substantial differences. Large countries such as China, India, Indonesia and Brazil get consistently lower allocations under the country level approach for the obvious reason that there is no scaling variable. Two countries with the same per capita income will receive the same allocations regardless of their population.

Chart 1A. Cumulative emissions allocations, 2010-2050 (gigatons)

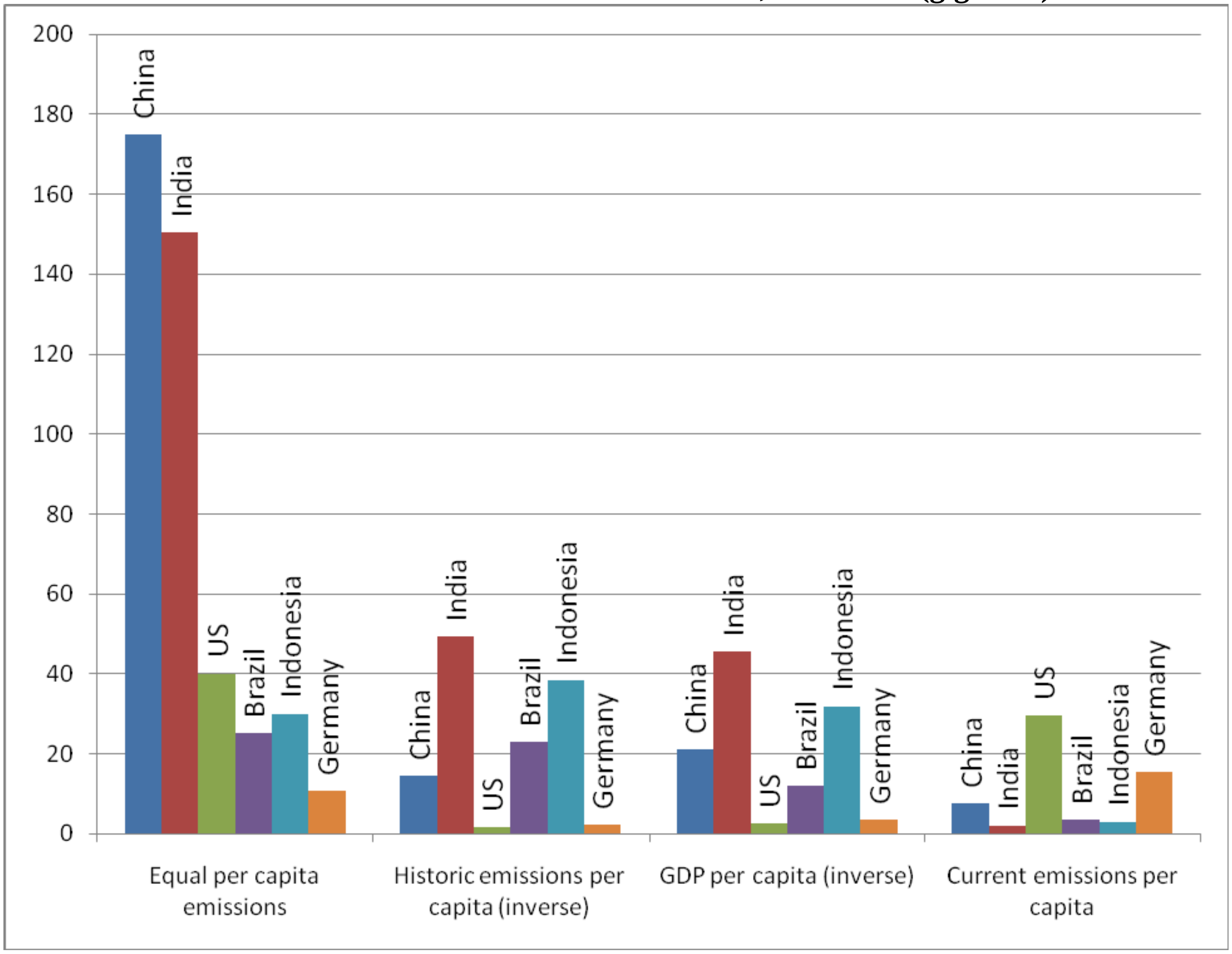
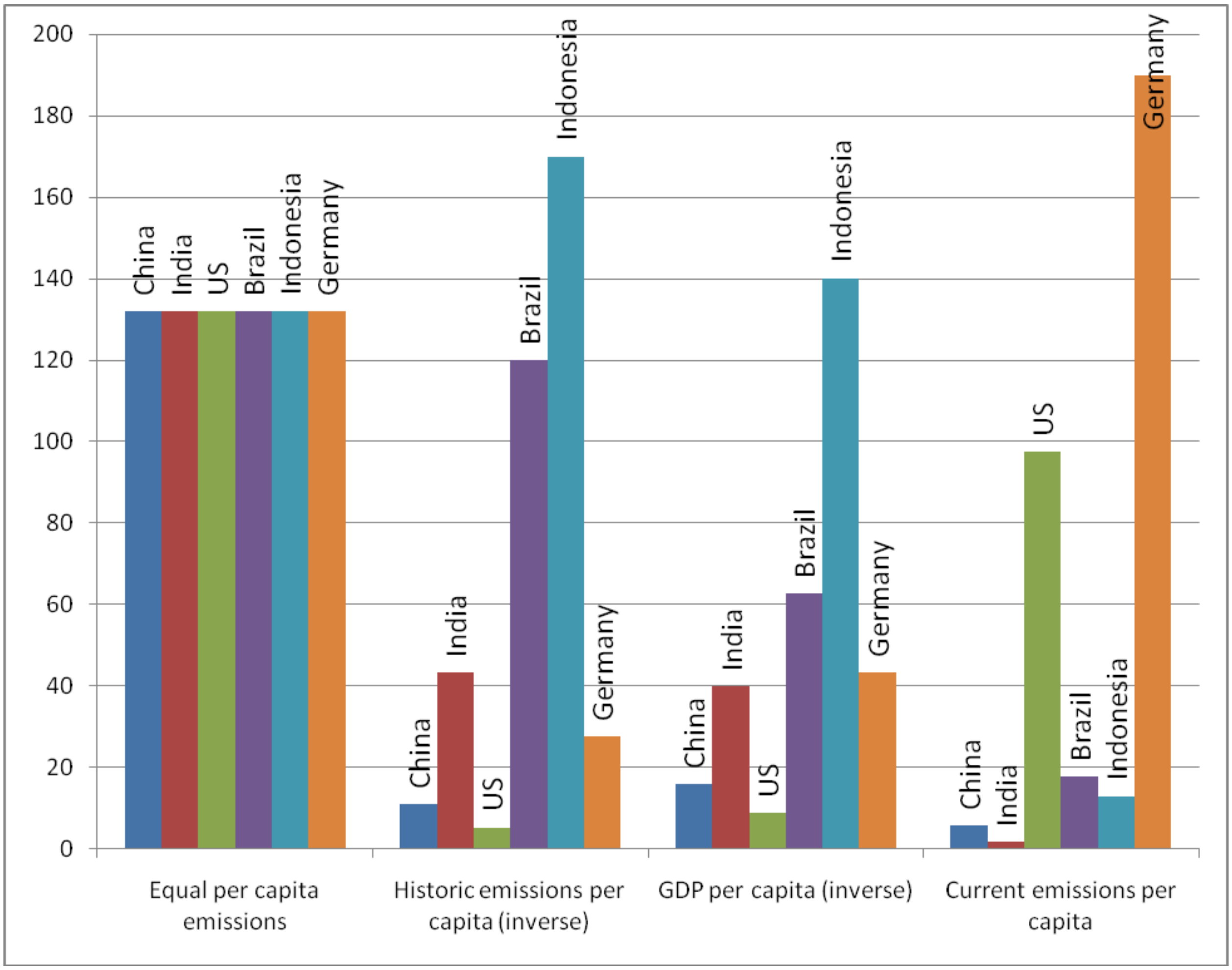


Chart 1B. Cumulative emissions allocations, 2010-2050 (gigatons)

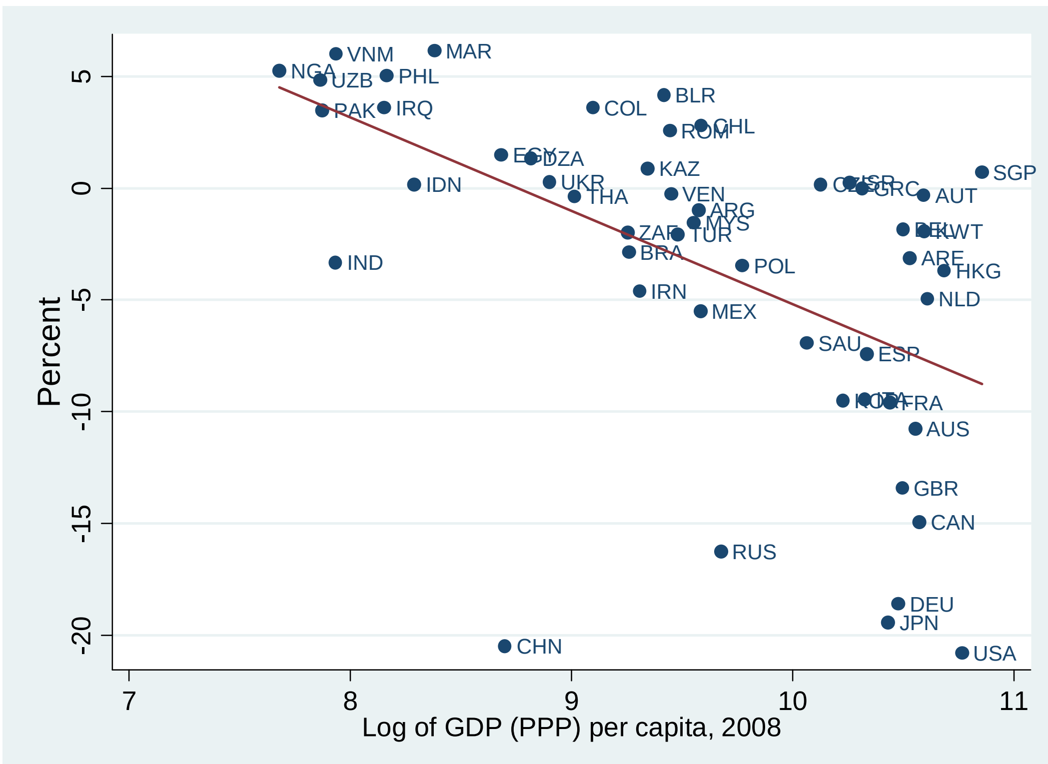


Note: With one exception, both charts show allocations for the major countries if each of the principles were the sole basis for allocations (i.e. as if the alphas in equation 9 in the text were set to one).

We next illustrate the impact of one of the proposals based on the country level approach on emissions allocations relative to BAU (analogous to Chart 4C in the text). Here emissions allocations to a country depend only on a country's per capita GDP, or more specifically on its inverse share of GDP per capita. This is exactly one the scenarios considered in Jacoby et. al (2007).[22]

[22] They, however, measure GDP per capita at market exchange rates and their sample is a combination of countries and regions.

Chart 2. Implications of ability-to-pay principle
Change in emissions growth compared to business-as-usual (annual average % between 2010 and 2050)



Note that in the chart above (as in Chart 3B in the text), the relationship is downward sloping. But the relationship when allocations start with the country as unit (as in the chart above) is much less equitable because the correlation with income is -.54 compared with a correlation of -0.95 when allocations start with the individual is the unit of analysis. The big difference is in the magnitudes of the reduction in emissions growth which is substantially greater for countries such as China and India. For example, under the individual level approach, China's emissions growth declines relative to BAU by -3 percent but under the country level approach it declines by over 20 percent. The comparable numbers for India are 3.5 percent and -3.3 percent, respectively. The regressive nature of the country level approach is also revealed when we compute the weighted average decline in emissions (where the weights reflect both a country's population share and GDP per capita share (inverse). This weighted average decline is -5.3 percent under the country level approach and 0.17 percent under the individual level approach. It must be noted that this

difference arises even though both use the same principle for allocation (ability-to-pay) and quantified it in the same way (inverse share of per capita GDP).
This contrast between the individual and country level approaches has not been adequately recognized in the literature but it is an important one that has come up in discussions in other contexts, most notably the allocation of quotas in the IMF and what the appropriate formula ought to be (see Bryant (2010) for a discussion).

Which of these two is the better approach? While the country-level approach is favored by most contributions, there may be reasons to begin with the individual as the unit of analysis. Ultimately, people have rights and countries' rights and obligations derive from individuals (see Stern (2007)).[23] Further, it seems more intuitive and consistent to specify the principle when the unit is the individual. For example, consider two states within the United States, say California and Rhode Island. If emissions were being allocated across states, it seems more likely that an individual level approach—which treated all Americans rather than all states as equal—would be favored. There are no ethical reasons why the same should not apply across countries.

[23] Note that the thought experiment we are doing is very similar—in the sense of starting with individuals—to the thought experiment that Stern (2009) suggests we undertake when thinking about the appropriate discounting of the future.

Appendix 3: Correlations between principles

The table below shows the pair-wise correlations between each of the four principles discussed in equation 9 in the text.

	Population	Inverse cumulative emissions per capita	Inverse GDP per capita	Current emissions per capita
Population	0			
Inverse cumulative emissions per capita	0	1		
Inverse GDP per capita	0	0.849	1	
Current emissions per capita	0	-0.5016	-0.5288	1

Appendix Table 1: Data and Their Sources

Variable	co2_emission_mil_mettons_2008	pop_2008	gdp_ppp_percap2008	mtco2e_1970to2006	g_bau	e_bau
Description	Carbon dioxide emissions	Population in year 2008	Gross domestic product per capita	Cumulative carbon dioxide emissions from 1970 to 2006	Per capita GDP growth in business-as-usual	Carbon dioxide emissions in business-as-usual
Unit	in millions metric tons	in millions	in US dollars	in metric tons carbon	in %	in %
Source	World Bank (WB) World Development Indicators (WDI)	World Bank (WB) World Development Indicators (WDI)	International Monetary Fund (IMF) World Economic Outlook (WEO), April 2010	Climate Analysis Indicator Tool (CAIT) World Resources Institute (WRI)	Birdsall and Subramanian (2009)	Birdsall and Subramanian (2009)
Country						
China	6,534	0	5,999	89,775	4.1	1.1
US	5,833	0	47,393	185,369	1.7	0.8
Russia	1,729	0	15,941	69,225	3.1	0.0
India	1,495	0	2,790	22,768	5.2	2.8
Japan	1,214	0	33,957	38,639	2.1	-0.6
Germany	829	0	35,539	35,713	2.3	0.1
Canada	574	0	39,080	16,640	1.9	0.5
UK	572	0	36,233	20,995	2.3	0.3
Korea_Rep	542	0	27,681	9,457	2.4	-0.2
Iran	511	0	11,026	7,614	3.6	2.0
Saudi Arabia	466	0	23,489	6,316	2.7	1.9
Italy	455	0	30,520	14,651	2.2	-0.3
South Africa	451	0	10,442	9,301	3.6	1.1
Mexico	445	0	14,528	10,214	3.3	2.1
Australia	437	0	38,356	9,486	1.9	0.6
Indonesia	434	0	3,980	5,812	4.8	2.8
Brazil	428	0	10,512	8,215	3.5	1.9
France	415	0	34,204	15,085	2.3	0.2
Spain	359	0	30,815	8,357	2.1	0.0
Ukraine	350	0	7,342	18,306	3.8	0.8
Poland	299	0	17,556	13,134	2.3	0.5
Turkey	272	0	13,107	4,897	3.8	2.0
Netherlands	264	0	40,558	5,966	2.3	0.0

Appendix Table 1 (contd.): Data and Their Sources

Variable	co2_emission_milmettons_2008	pop_2008	gdp_ppp_percap 2008	mtco2e_1970to2006	g_bau	e_bau
Description	Carbon dioxide emissions	Population in year 2008	Gross domestic product per capita	Cumulative carbon dioxide emissions from 1970 to 2006	Per capita GDP growth in business-as-usual	Carbon dioxide emissions in business-as-usual
Unit	in millions metric tons	in millions	in US dollars	in metric tons carbon	in %	in %
Source	World Bank (WB) World Development Indicators (WDI)	World Bank (WB) World Development Indicators (WDI)	International Monetary Fund (IMF) World Economic Outlook (WEO), April 2010	Climate Analysis Indicator Tool (CAIT) World Resources Institute (WRI)	Birdsall and Subramanian (2009)	Birdsall and Subramanian (2009)
Country						
Thailand	254	0	8,232	3,576	5.0	2.3
UAE	199	0	37,442	1,956	3.0	1.4
Kazakhstan	199	0	11,434	7,611	5.0	1.0
Venezuela	184	0	12,717	3,981	3.8	2.1
Argentina	172	0	14,408	4,127	3.8	2.4
Egypt	165	0	5,897	2,951	4.3	2.7
Malaysia	162	0	14,082	2,310	4.8	3.1
Singapore	159	0	51,846	932	4.8	0.3
Belgium	155	0	36,345	4,517	2.2	0.2
Pakistan	148	0	2,624	2,258	5.4	4.5
Uzbekistan	125	0	2,599	4,448	5.0	3.4
Greece	107	0	30,189	2,498	2.2	-0.1
Algeria	106	0	6,753	2,142	5.5	4.6
Romania	103	0	12,638	5,231	3.9	1.0
Czech Republic	102	0	25,061	5,458	2.3	-0.4
Iraq	101	0	3,477	2,021	4.8	4.1
Nigeria	100	0	2,162	2,116	5.4	5.7
Vietnam	94	0	2,794	1,190	4.9	3.0
Hong Kong	84	0	43,754	1,344	4.8	2.7
Kuwait	82	0	39,941	1,471	2.7	1.6
Philippines	80	0	3,515	1,750	4.8	3.4
Austria	70	0	39,887	2,223	2.2	-0.1
Israel	70	0	28,474	1,334	2.4	1.2
Belarus	68	0	12,313	3,130	3.8	0.9
Colombia	65	0	8,928	1,778	3.8	2.6
Chile	65	0	14,592	1,252	3.2	1.8
Morocco	40	0	4,362	844	5.6	3.5

Note: For historic emissions, Hong Kong's was assumed to be the same in per capita terms as Singapore. Emissions for some of the Former Soviet Union countries for the early 1990s were extrapolated backwards.

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