



Comparing climate strategies: Economic optimization versus equitable burden-sharing

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Abstract

Climate policy addresses a global problem, with costs and benefits distributed unevenly around the world. Questions of efficiency and equity are central to the allocation of costs; they are typically handled either by modeling optimal policies based on economic efficiency, or by setting standards that embody principles of equity.

In this analysis, we employ our Climate and Regional Economics of Development (CRED) integrated assessment model to assess the optimal international allocation of effort. We compare CRED scenarios to the results of an equity-oriented burden-sharing framework, Greenhouse Development Rights (GDRs), which allocates effort to countries based on their responsibility (emissions) and capacity (income).

We calibrate CRED to generate a scenario comparable to the GDRs reference case, or business as usual. We then recalibrate CRED to generate a mitigation scenario comparable to the GDRs emergency reduction scenario, which preserves a high likelihood of staying below 2°C. Finally, we compare the share of global effort allocated to high-income countries in the CRED mitigation scenario and the GDRs emergency reduction scenario, finding them to be similar in both models.

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Introduction

Climate change is the ultimate global public good (or public bad): the severity of the problem depends on total world emissions, so anyone's greenhouse gas emissions affect everyone. The impacts, however, are unevenly distributed, often falling most heavily on the hottest and poorest countries. The capacity to deal with the problem may be even more unequally distributed, since the response requires significant investments in mitigation and adaptation.

Thus the discussion of climate policy naturally includes a focus on questions of international equity. In order to reach agreement on coordinated global action to address this global externality, some agreement on burden-sharing is necessary. In only slightly oversimplified terms, how much of the global cost of climate protection should rich and poor countries pay?

This fundamental question has been answered from at least two different perspectives: from the realm of international negotiations, and from economic modeling. Proposals for international agreements frequently begin with principles of equity and advocate their use to set standards and allocate costs. Many economic models, on the other hand, calculate optimal scenarios, using frameworks in which the optimization criteria are focused on economic efficiency, though they may implicitly or explicitly incorporate notions of equity.

How different are the results of these two approaches in practice? In this analysis we assess the international equity implications of our Climate and Regional Economics of Development (CRED) model – specifically exploring the distribution of the mitigation effort required to meet a stringent climate constraint. CRED is a relatively simple and transparent integrated assessment model, designed to explore optimal scenarios under differing assumptions about international burden-sharing. As a benchmark for comparison, we use the Greenhouse Development Rights (GDRs) framework, a normative, principle-based burden-sharing approach that has been widely discussed in the context of recent climate negotiations.

In Section 2, we elaborate on the underlying assumptions of the two styles of analysis. Section 3 describes CRED and GDRs. Section 4 presents a three-step comparison of the two approaches: first, we calibrate CRED to yield a scenario comparable to the GDRs reference (business-as-usual) scenario; then we recalibrate CRED to a 2°C mitigation pathway, comparable to the GDRs emergency reduction scenario; finally, we compare the “optimal” allocation of mitigation effort found by CRED to the “equitable” allocation of effort prescribed by GDRs. The conclusions in Section 5 discuss the results, and identify the common implications of the two approaches. Under either GDRs or CRED assumptions, equitable resource distribution leads to better climate outcomes; economic growth and climate stabilization are only rival objectives in the politics of high-income countries, not in the world as a whole.

The multiple meanings of climate equity

Principles and proposals

Equity, as it applies to climate policy, is not a single, precisely defined concept. According to Heyward (2007), it involves three broad principles: equality and equal treatment of individuals or nations; the “polluter pays” standard, or responsibility for solving problems created by one’s own actions; and ability to pay, or capacity to contribute to global solutions. Lange et al. (2007), meanwhile, identify four dominant approaches to equity in ongoing debates: the goal of equal per capita emissions; equal percentage reductions in current emissions; the polluter-pays rule, implying allocation of abatement costs in proportion to current or historical emissions; and ability to pay, sometimes including an exemption from all costs for those with the lowest incomes.

Proposals for international climate agreements frequently rely on one or more of these principles. The Kyoto Protocol instituted a system of “common but differentiated responsibility,” in which developed countries committed to similar (though not identical) percentage reductions from their 1990 emissions, while developing countries had no reduction requirements in the first commitment period (through 2012). The “contraction and convergence” proposal calls for a gradual reduction (contraction) in global average per capita emissions, and sets emissions caps for individual countries, converging from current emissions to equal per capita emissions by a target date, such as 2050. The “Brazilian proposal,” made during the Kyoto negotiations, bases responsibility for reductions on historical contributions to greenhouse gas emissions. The GDRs framework, discussed below, builds on and extends the approaches of earlier proposals. Although it is not logically necessary, an international carbon market is often assumed to accompany such standards, allowing countries to supplement their domestic reductions with emission reduction credits purchased abroad. In that context, lower emission caps for rich countries would lead them to make larger investments in emission reduction in lower-income countries.

Equity implications of optimization models

Climate equity looks quite different from an economic perspective. Economists often say that efficiency can be separated from equity, suggesting that efficiency – producing the maximum output with the available resources – is the subject of economics, while concerns with equity can be left to the political process. Along these lines, economic theory has, since the 1930s, maintained that it is unable to evaluate the distribution of income: while each individual displays diminishing marginal utility for consumption, there is said to be no way to compare the satisfaction that different individuals obtain from the same goods or income. Strict adherence to this principle leads to the unsatisfying result that Pareto optimality is the sole criterion for approving public policies and resource reallocations.¹ This amounts to a strong bias in favor of the status quo, because change is only possible by unanimous consent.

In practice, Pareto optimality provides little guidance for quantitative modeling of policy problems such as climate change. Modelers have frequently reverted to the utilitarianism that was in vogue before the 1930s, assuming that the optimal policy is the one that maximizes a social welfare function

¹ Pareto optimality means that no one can be made better off without making someone else worse off.

(see Ackerman, Stanton, et al. 2010 for more extensive discussion)(see Ackerman, Stanton, et al. 2010 for more extensive discussion). Although more complicated welfare functions can be created (e.g. Anthoff and Tol 2010), the simplest and most common approach involves an unweighted sum of individual utilities. Everyone is assumed to have the same utility function, where utility is a concave function of consumption.² The social welfare function is the sum of all individual utilities.

This mathematical apparatus should impart a strong preference for equal distribution of resources. The equal weight of each individual, expressed in the summation of identical utility functions, and the diminishing marginal utility of consumption, together imply that social welfare is maximized by distributing consumption goods equally to all. Consider the following example: Assume that changes in utility are proportional to *percentage* changes in consumption, so that everyone, rich or poor, gains the same satisfaction from a 1-percent increase in spending. Now suppose that A consumes \$10,000 while B consumes \$1,000. According to the assumed utility function, the two-person society of A and B would be 16 percent better off if A gave \$4,500 to B, so that each could consume \$5,500.³ In terms of the multiple principles of equity discussed above, this utilitarian preference for redistribution is based solely on equal treatment of individuals and their ability to pay, or relative incomes.

Why doesn't the preference for redistribution show up in most integrated assessment models (IAMs) of climate economics? Some models, such as PAGE, are not optimization models, and some, such as DICE, do not disaggregate the world into separate regions. Among multi-region optimization models, there are two factors that obscure the redistributive implications of a concave utility function, one institutional and one technical. The obvious institutional answer is that many models do not include the option of transferring resources between regions, or having one region pay for abatement in another region. The hidden technical answer is that complex models frequently rely on "Negishi weights," which suppress any tendency toward redistribution (Stanton 2010). Negishi (1972) outlined a procedure for solving complicated general equilibrium models, by assuming that everyone had the same marginal utility of consumption – thus undoing the egalitarianism that is embodied in the welfare function, and finding a solution consistent with the existing distribution of income.

CRED and GDRs

Climate and Regional Economics of Development (CRED)

CRED is a relatively new IAM, developed at the Stockholm Environment Institute (see Ackerman, Stanton, et al. 2010 for a complete model description). It is designed at the same level of complexity as the simpler existing models, such as DICE (described in Nordhaus 2008), for policy relevance and ease of use. Selected features are borrowed from DICE, although the differences are more important than the similarities. The major innovations in CRED are the explicit incorporation of diminishing marginal

² That is, the first derivative of utility (the marginal utility of consumption) is always positive, and the second derivative is always negative (implying that marginal utility is diminishing).

³ Under the assumptions described here, utility is proportional to the logarithm of individual consumption. The conclusion about A and B follows from the fact that $2.00 * \log(5,500) = 1.16 * (\log(10,000) + \log(1,000))$. Logarithmic utility is the least egalitarian, in its implications, of commonly used utility functions; other common assumptions would imply a gain of more than 16 percent from equalization between A and B.

utility, the potential for resource transfers between regions, and the use of the McKinsey cost curves to estimate abatement costs.

CRED measures individual utility as the logarithm of per capita consumption; social welfare is the sum, across all regions, of (population * log (per capita consumption)). The optimal scenario is the one that maximizes the present value of welfare, summed over the entire multi-century period of analysis. In order to maximize welfare, CRED determines the level of savings, and the use of those savings, for each region and time period. Each region's savings can be used for investment either at home or abroad; in any location, savings can go into high-productivity standard investment, or into lower-productivity green investment, which reduces emissions but produces less income.

With no constraints on the export of savings, CRED produces an extreme result: welfare is maximized, and climate change is controlled most effectively, by allowing high-income consumption levels to fall to the level of middle-income nations, while dedicating most of the world's savings to investment in developing regions. This is well outside the realm of realistic policy proposals; most CRED scenarios are therefore constrained to guarantee a positive rate of growth in per capita consumption in every region, and to include a limit on the fraction of a region's output that can be transferred to other regions. While making CRED sound less unrealistic, these constraints lower the present value of global welfare, and lead to worse climate outcomes.

Greenhouse Development Rights (GDRs)

The GDRs framework, widely discussed in climate policy circles since its introduction in 2008, takes a novel and straightforward approach to climate equity (Baer et al. 2008). Its starting point is the recognition of the climate crisis, which has become a global emergency; the only solution involves the mobilization of resources needed to achieve a rapid transition to a low-carbon economy. At the same time, the need for development in the global South, and the progress already under way in many countries, threatens to increase energy use and greenhouse gas emissions. To be successful, a climate agreement will have to distribute the costs of reducing emissions in a manner that is fair to all, while preserving the right to development for those who are still in poverty.

Accordingly, GDRs codifies the right to development as a “development threshold” – a level of welfare below which people are not expected to share the costs of the climate transition. The GDRs default threshold is \$20 per person per day, or \$7,500 per person per year (in purchasing power parity terms). This is a level at which basic needs can be met, but middle-class consumption patterns have not yet begun. People above that threshold are taken as having realized their right to development; the capacity to participate in the costs of climate protection is proportional to the amount of an individual's income above the threshold. That capacity is based on individual, not national, income levels: the wealthy minority in poor countries is expected to contribute, while the impoverished minority in rich countries is not.

Responsibility for the climate crisis, in the GDRs framework, is proportional to cumulative emissions since 1990, excluding emissions that correspond to consumption below the development threshold –

again defined on an individual rather than national basis.⁴ A weighted average of responsibility and capacity yields a “responsibility capacity index” (RCI). The global emission reductions that are required for climate protection are then allocated in proportion to the RCI. Given the global nature of the problem, it does not matter whether a country carries out its emission reductions at home or abroad. Indeed, high-income countries are presumed to do some of both.

One example may suggest the significance of this approach: The United States and China have similar total emissions, but very different levels of capacity and responsibility. In 2010, the United States has 33.1 percent of global RCI (and hence, should carry out that percentage of global abatement), while China has 5.5 percent. By 2030, the U.S. share is projected to fall to 25.5 percent of the world total, while China’s share is expected to reach 15.2 percent (Baer et al. 2008, p.19).

Comparison of results

Framework for comparison

While both GDRs and CRED can produce multiple scenarios, CRED has many more user-specified inputs; GDRs has a standard pair of scenarios (the reference scenario and the emergency reduction scenario) that anchor its calculations. Therefore, our comparison is based on finding CRED scenarios that most closely match the two GDRs scenarios.

In effect, we are asking, under what assumptions would each of the GDRs scenarios be optimal according to CRED? Using the CRED scenario that approximates the GDRs emergency reduction scenario, we then ask a second question: how do the mitigation burden-sharing recommendations of CRED and GDRs compare?

There are several issues of units and conversions required for quantitative comparison. We have converted CRED emissions data to MtCO₂/year, to match GDRs data. We use CO₂ emissions alone (sum of fossil plus land-use emissions), to avoid inconsistent treatment of other greenhouse gases. GDRs’ reporting years extend only to 2030; CRED reports every ten years starting in 2005. We have constructed 2030 estimates in CRED, as the average of the 2025 and 2035 results, for comparison to GDRs’ 2030 figures.

GDRs reports data for individual countries and for several groupings of countries, while CRED aggregates countries into nine regions. The countries included in CRED’s three high-income regions are almost, although not exactly, the same as the membership of the OECD.⁵ We have compared the CRED high-income regions to GDRs estimates for the OECD.

GDRs uses a single scenario for GDP and two scenarios for emissions; reference case emissions are based on the International Energy Agency’s World Energy Outlook, while the emergency reduction scenario is the pathway required to maintain a high likelihood of staying under 2°C of warming. The summary data, for the world, under these scenarios are as follows:

⁴ Baer et al. (2008) convert the individually assigned capacity and responsibility into national totals, using estimates of income distribution within countries.

⁵ CRED high-income regions exclude OECD members Chile, Israel, and Mexico, but include the non-OECD members of the European Union: Bulgaria, Cyprus, Latvia, Lithuania, Malta, and Romania.

	GDP, billion \$2005	CO2 emissions (million tons)	
		Reference	Reduction
2010	48,842	33,753	33,753
2015	57,165	37,825	33,037
2020	66,097	40,139	25,337
2025	75,640	42,958	18,517
2030	85,793	45,989	13,493
<i>Growth rate</i>			
2010-30	2.9%	1.6%	-4.5%

CRED match to GDRs reference scenario

Our first goal was to find CRED scenarios that provide an approximate match to these world totals. In this process, we modified four key parameters in CRED:

- The rate of pure time preference, a key component of the discount rate.⁶ The CRED default is 0.1% per year, the value used in the Stern Review.
- The climate sensitivity parameter, measuring the temperature change expected from a doubling of the atmospheric concentration of carbon dioxide. CRED’s default value of 4.5°C, the upper end of the IPCC’s “likely” range, expresses a precautionary approach to the pace of change. A more common value is 3.0°C, which is identified as the most likely value in many past studies.
- The damage function coefficient, governing the costs imposed on the global economy by rising temperatures. The CRED default is slightly more than twice the level assumed in the well-known DICE model.⁷
- Resource transfers: CRED allows income from one region to be transferred to another region for investment; a user-specified cap limits such transfers (outflows) to no more than a fixed percentage of regional output.

The pattern of global emissions in the GDRs reference scenario roughly matches the global emissions in a CRED scenario with:

- Pure time preference = 2.2%
- Climate sensitivity = 3.0
- Damage coefficient = 0.006 (i.e., the CRED default)
- No transfers of resources between regions

⁶ Pure time preference is the discount rate that would apply if real per capita consumption were constant over time; the widely used “Ramsey equation” defines the discount rate as the sum of pure time preference plus a component based on the growth of per capita consumption.

⁷ CRED uses the same functional form as DICE: Output net of climate damages = Gross output / (1 + aT²), where T is warming in °C. DICE uses a = .0028; the CRED default is a = .006.

Under these assumptions about the world, CRED’s optimal scenario would roughly match the global emissions path in the GDRs reference scenario. The emissions comparison (in millions of tons of CO₂ per year) is as follows:

	GDRs	CRED	difference
2005	33,160	32,574	-1.8%
2015	37,825	41,495	9.7%
2025	42,958	42,317	-1.5%
2030	45,989	43,410	-5.6%

In other words, CRED finds that the GDRs reference scenario is close to the optimal climate and economic outcomes (i.e., the scenario that maximizes the present value of human welfare), assuming a moderately high discount rate, the conventional value for climate sensitivity, a moderate rate of climate damages, and no willingness of rich countries to invest in mitigation in poor countries. Under these assumptions, CRED’s “optimal” scenario never stabilizes the climate: the atmospheric CO₂ concentration and temperature both rise steadily throughout the 200-year forecast period, reaching very dangerous levels. This corresponds to (or formalizes) the common intuition that business as usual is leading toward disastrous climate change.

CRED match to GDRs emergency reduction scenario

CRED does not appear to match the GDRs emergency reduction scenario as closely as it does the reference scenario. A CRED scenario with a pace of overall emission reduction similar to the GDRs emergency reduction scenario can be created with

- Pure time preference = 0.1%
- Climate sensitivity = 4.5
- Damage coefficient = 0.011 (four times the DICE level, as suggested by recent research by Michael Hanemann⁸)
- Resource transfers allowed to reach up to 5% of the donor region’s output.

The GDRs time path of reductions, with 2015 emissions almost identical to 2005, followed by rapid reductions thereafter, is very difficult to match precisely in CRED. (See comparison of annual emissions in table below.) However, the match in terms of cumulative emissions from 2005 to 2030 (using linear interpolation between the reported years) is quite reasonable, with the CRED scenario being 13.4% below the GDRs scenario.

⁸ Hanemann (2008) reviews the components of the DICE damage function in detail, as applied to the United States, and finds that four times the DICE level would be a more reasonable estimate of climate damages.

	GDRs	CRED	difference
2005	33,160	32,574	-1.8%
2015	33,037	24,805	-24.9%
2025	18,517	16,216	-12.4%
2030	13,493	16,316	20.9%

In short, CRED finds that a scenario somewhat comparable to the GDRs emergency reduction pathway is optimal, under the assumptions of a low discount rate, a high, precautionary value of climate sensitivity, a higher-than-conventional (but quite believable) forecast of climate damages, and a moderately large willingness of rich countries to invest in mitigation in poor countries.

The CRED scenario described here reaches a maximum temperature of 1.96°C above 1900, in 2095. Atmospheric CO₂ concentration remains nearly constant at 398-405 ppm from 2015 to 2085, before declining. Thus its climate results are broadly similar to the GDRs emergency reduction scenario, adding to the sense that these are comparable climate trajectories.

Comparing obligations for global mitigation

Using the GDRs emergency reduction scenario and the matching CRED scenario, we then compared the share of global obligation for abatement assigned to OECD countries (in GDRs) or the high-income regions (in CRED). In GDRs, we calculated obligation as the difference between reference scenario and emergency reduction scenario emissions. In CRED, we calculated responsibility as domestically funded abatement plus the share of other regions’ abatement financed by resource transfers from a region. The two scenarios converge to very similar responsibilities – approximately 60% – assigned to the high-income countries by 2030.

Shares of global responsibility		
	OECD (GDRs)	High-income (CRED)
2015	73.9%	47.8%
2025	65.2%	59.6%
2030	60.2%	60.8%

Conclusions

Using an economic optimization that maximizes global utility, CRED generates an allocation of global effort quite comparable to GDRs, which uses a normative burden-sharing approach based on capacity and responsibility. This result is derived by calibrating CRED to a reference scenario and 2°C mitigation scenario that are both broadly similar to those on which the GDRs analysis is based, and comparing the allocation of global effort. The reference scenario used in the GDRs analysis is reproduced by CRED using conventional assumptions, a moderately high discount rate, and no resource transfers between regions. This reference scenario implies runaway climate change, with increasingly unacceptable outcomes to be expected within a matter of decades. The 2°C emergency

reduction used in the GDRs analysis is roughly reproduced by CRED using precautionary assumptions, a low discount rate, and reasonably large resource transfers between regions. This scenario brings climate under control by the end of this century, and improves thereafter.

Both CRED's optimization and GDRs' burden-sharing approaches lead to a high-income share of about 60% of global responsibility by 2030. CRED gets there more gradually, ramping up from 48% in 2015. GDRs starts with high-income responsibility at 74% of the total in 2015, dropping to 60% by 2030.

The striking result here is that the equity-based approach and the economically optimal approach are ultimately quite consistent. Largely, this result is a reflection of the fact that both approaches imply large transfers from the wealthy countries to the poorer. In GDRs, these transfers are justified by the fact that the majority of the world's capacity and responsibility reside in the wealthy countries. In CRED, these transfers are justified by a straightforward implementation of the notion of declining marginal utility of income. In other words, it is more efficient (in the case of CRED) and more equitable (in the case of GDRs) for much of the mitigation that is needed in the poorer countries to be financed by the wealthy countries.

Thus there is no conflict, for the world as a whole, between efficient economic growth and optimal climate outcomes. This result has different implications for high-income and low-income countries. In low-income countries, growth would be accelerated by investment (of savings from high-income countries) in mitigation, while high-income countries would experience correspondingly lower growth. Under both the GDRs and the CRED approach, growth and climate protection are rival objectives in high-income countries, which are called upon to share their resources to enable a global climate transition. The political difficulties of this are obvious, and the crucial, still unresolved questions are: how far from the global welfare and climate optimum is it necessary to deviate in order to win acceptance of climate policy in high-income countries? How far from the optimum is it possible to deviate, and still stabilize the climate? And most important, how much, if at all, do the answers to the previous two questions overlap?

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