Climate policy and development: an economic analysis

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Abstract

We use the Climate and Regional Economics of Development (CRED) model to explore the interconnections between climate and development policy. CRED scenarios, based on high and low projections of climate damages, and high and low discount rates, are used to analyze the effects of varying levels of assistance to the poorest regions of the world.

We find that climate and development choices are nearly independent of each other if the climate threat is seen as either very mild or very serious. The optimal climate policy is to do very little in the former case, and a lot in the latter case, regardless of development. In the latter case, however, assistance may be required for the poorest regions to respond to serious climate threats in the globally "optimal" manner. Under intermediate assumptions about the severity of climate risks, development policy plays a greater role. In one scenario, which falls within the range of current debate, a high level of development assistance makes the difference between success and failure in long-term stabilization of the global climate.

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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 significant investments in mitigation and adaptation will be required.

The tradeoff between investment in climate protection and investment in economic growth will be evaluated differently by countries at different income levels. At higher incomes, additional economic growth is less urgent, and climate investments will often be more acceptable (although in practice, high-income countries differ greatly in their willingness to make such investments, for reasons beyond the scope of this article). At lower incomes, it is more urgent to raise average standards of living, so countries may be less willing to sacrifice immediate growth for long-run climate goals. This argument rests on the declining marginal utility of income, a thoroughly orthodox (and intuitively plausible) principle of economic theory.

The interaction between climate policy and development has been widely discussed (see, e.g., F. Ackerman, Kozul-Wright, et al. 2012), leading to innovative proposals for international equity in climate policy (Kartha et al. 2009). Yet economic analysis of climate change has often overlooked questions of equity and development – either through overly aggregated analysis of the world as a whole, or through the use of modeling techniques that ignore differences in marginal utility between rich and poor (Stanton et al. 2009; Stanton 2011). Such analyses identify "optimal" climate policies in isolation from the inescapable pressures of inequality and the need for development.

In this article we use the Climate and Regional Economics of Development (CRED) model to explore the interconnections between climate and development policy. We identify some circumstances under which climate and development policy display virtually no interaction, and other circumstances under which development choices are decisive for climate outcomes.

Broadly speaking, we find that climate and development choices are nearly independent of each other if the climate threat is seen as either very mild or very serious. The optimal climate policy is to do very little in the former case, and a lot in the latter case, regardless of development – although in the latter, arguably realistic, case, international equity concerns may still affect the political feasibility of the optimal policy (Kartha et al. 2009). Under intermediate assumptions about the severity of climate risks, development policy plays a greater role. In one of our scenarios, which falls within the range of current debate, a high level of development assistance makes the difference between success and failure in long-term stabilization of the global climate.

The CRED model

CRED is an integrated assessment model (IAM), created by the Stockholm Environment Institute (Ackerman et al. 2011; 2012). Like many IAMs, it calculates the policy choices that maximize a utility function, and spells out the long-run climate and economic implications of those choices. One crucial technical choice in CRED is that utility is based on the logarithm of the level of consumption.[4]

The utility function embodies the principle of declining marginal utility[5], and is the key to CRED's approach to equity and development. All else being equal, the same absolute increase in consumption is more valuable – it adds more to global utility – if it occurs in a lower-income region. Specifically, logarithmic utility implies that equal *percentage* changes in consumption, at any income level, create equal changes in utility. The 16 regions used in CRED v1.4 are shown in Table 1, with their per capita consumption levels in 2010 (at market exchange rates, not purchasing power parity[6]). These data imply that $1 of additional consumption in India creates the same amount of utility as $7 in Eastern Europe or $38 in the United States.

The central economic decision modeled in an IAM is the three-way choice between current consumption, conventional investment, and investment in emission reduction. Conventional investment stimulates economic growth, leading to greater future consumption; mitigation of emissions limits future climate damages, also allowing greater future consumption; there is a tradeoff between current consumption and both routes to future consumption. The sequence of decisions that maximizes utility depends on the discount rate, and on many other climate and economic parameters.

In view of the inequality among regions of the world, another dimension of choice could be considered: where should investment occur? Global utility might be increased if investment from rich countries went to poor countries instead of staying at home. Is investment 38 times as productive, in monetary terms, in the United States as in India? If not, then it could be more productive, in terms of utility, to invest in India.

CRED is designed to explore this spatial dimension of decision-making, by allowing resource transfers, or capital exports, from one region to another. (No return flows of income on exported capital are modeled; the transfers can be thought of either as foreign aid grants, or as foreign direct investment with 100 percent local reinvestment of earnings.) With no constraints on the extent of transfers, the optimal scenario simultaneously achieves robust global economic growth and rapid emission reduction. This creates higher worldwide utility, greater equality, and better climate outcomes than any other scenario – at the expense of a steep drop in the standard of living in high-income regions, down to global middle-income levels. Thus the scenario with unconstrained transfers, while analytically informative, is irrelevant to practical policy debates.

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[4] A region's utility is the log of its average per capita consumption, multiplied by regional population. Global utility is the sum of regional utilities; CRED maximizes the present value of global utility over the 300-year span of its scenarios. This is well within the range of corresponding assumptions in other integrated assessment models – it is a standard assumption, though it will be shown to have non-standard implications.

[5] If utility is $u(c) = \ln c$, then marginal utility $u'(c) = 1/c$, a declining function of c.

[6] CRED uses market exchange rates throughout, in order to facilitate calculation of interregional resource flows, discussed below.

Table 1. CRED regions: 2010 population and per capita consumption

	Per capita consumption *(thousand US$)*	Population *(millions)*
High income	***32.8***	***990***
USA	38.0	318
Japan	33.4	127
Westerm Europe	31.4	409
Other High Income	25.1	136
Middle income	***6.9***	***1252***
Other Europe	9.1	177
Brazil	8.9	195
Mexico	7.4	111
Eastern Europe	7.0	223
Middle East	5.6	215
Other Latin America/Caribbean	5.5	281
South Africa	5.4	50
Low income	***1.6***	***4685***
China	2.7	1361
Southeast Asia/Pacific	2.2	616
Other Africa	1.1	981
India	1.0	1214
Other Developing Asia	0.9	513

Definitions	
Western Europe	*EU-15, Iceland, Norway, Switzerland*
Other High Income	*Australia, Canada, New Zealand, Singapore, South Korea, Taiwan*
Other Europe	*EU except EU-15, Turkey*
Eastern Europe	*Russia, Ukraine, Belarus, Moldova, Albania, non-EU ex-Yugoslavia*
Middle East	*excludes North Africa, includes Iran*
Southeast Asia/Pacific	*Myanmar, Thailand, Malaysia, Cambodia, Laos, Vietnam, Indonesia, Philippines, island nations*
Other Africa	*includes North Africa*
Other Developing Asia	*Pakistan, Bangladesh, Nepal, Bhutan, Afghanistan, Mongolia, North Korea, Asian ex-USSR*

In order to focus on more realistic choices, two constraints are imposed on interregional resource flows in CRED. First, consumption per capita in every region must grow by at least 0.5 percent per year – indirectly requiring significant domestic investment. Second, there is a user-specified upper limit on the fraction of a region's output that can be transferred to other regions. With a limit of 3 percent, for example, CRED makes an unconstrained global calculation of the optimal use of the first 3 percent of a region's output, and then calculates the optimal domestic allocation of the remaining 97 percent to consumption, conventional investment, and mitigation. High-income regions are normally exporters of capital, and low-income regions are importers. Middle-income regions can either be importers or exporters of capital, depending on the scenario.

CRED contains a number of other innovations, including an updated climate module calibrated to recent research results, and abatement cost curves derived from the McKinsey database of projections for 2030. Steady technological change is assumed after 2030, expanding abatement opportunities to allow 100 percent mitigation of emissions in 2100 and thereafter. The expansion from 9 to 16 regions in the latest revision of CRED allows a more detailed and flexible analysis of global inequality and its interaction with climate change (F. Ackerman, Stanton, et al. 2012).

Climate modeling assumptions

CRED results can be contrasted under high and low choices for two key assumptions: the discount rate and the extent of climate damages.

For the discount rate, we compare a 0.1% rate of pure time preference[7], the rate used in the Stern Review (Stern 2006) with a 1.5% rate, which is used in DICE and some other climate economics models (Nordhaus 2008). Climate benefits accrue over the long run following investment in mitigation, so their present value is strongly affected by the discount rate. In contrast, development occurs more rapidly; in CRED, resource transfers typically lead to a new long-term global distribution of income within a few decades. As a result, development benefits are much less sensitive to the discount rate. Therefore a lower discount rate gives greater weight to climate protection, while a higher discount rate gives greater weight to development.

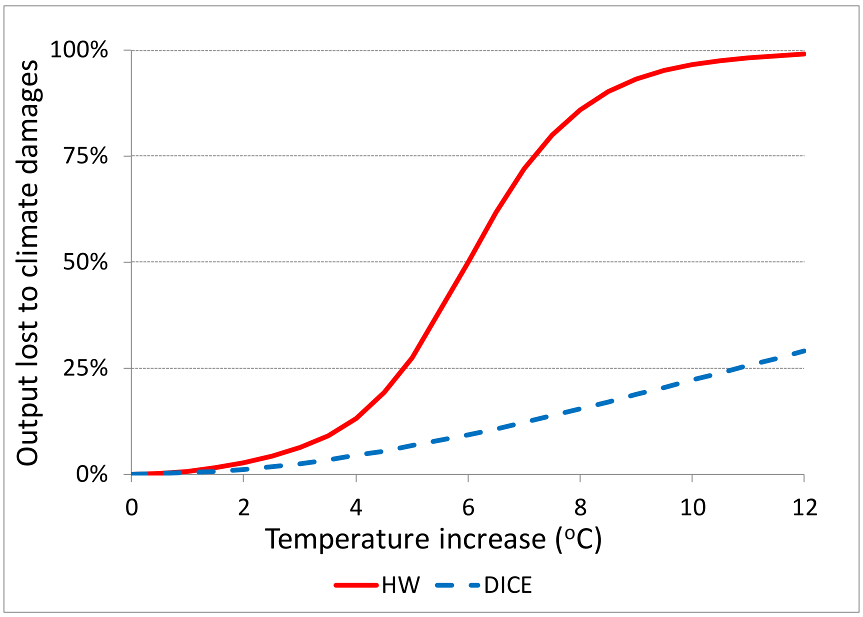

Figure 1. Two damage functions

For damages, we use two functions expressing the fraction of output lost to climate damages as a function of temperature increases (see Figure 1). The low estimate is the DICE damage function, in which damages are less than 2 percent of output at 2.5°C and rise only gradually thereafter, reaching 50 percent of output around 19°C. The high estimate, which we have dubbed the "HW" damage function, combines Michael Hanemann's re-estimate of damages at 2.5°C (amounting to

[7] The rate of pure time preference is the discount rate that would apply if all generations were equally wealthy, or equivalently, the discount rate that applies to utility rather than to monetary values. In CRED the discount rate for monetary values would be the rate of pure time preference plus the rate of growth of per capita consumption (although the only discounting that occurs in CRED is in the utility function).

2.4 times the DICE estimate) with Martin Weitzman's suggestion that risks of catastrophic climate losses can be represented by assuming 50 percent loss of output at 6°C, and 99 percent loss at 12°C (see Ackerman and Stanton 2012).[8]

Varying these two factors independently leads to four scenarios, for high and low discount rates, at DICE and HW damages. Within each scenario, we compare results with resource transfer limits of 0, 3 percent, 6 percent, and 10 percent of output. (Experiments with higher limits yielded greater equality and more rapid development, with climate results essentially indistinguishable from the 10 percent case.)

Development results

Economic growth in low-income regions is strongly dependent on the level of resource transfers between regions, but little affected by discount rates and damage assumptions. Using per capita consumption in 2100 as a measure of development, the results are shown in Table 2. (CRED projects little change in the relative incomes of high, middle and low-income regions after 2100; all continue to grow at similar rates.) Each figure in Table 2 is the average of the values under all four scenarios. Consumption is generally higher with the DICE damage function, which implies smaller climate losses, but the differences are not large; in all but one case, the estimates under the four scenarios differed by 15 percent or less.

Table 2. Consumption per capita by region, 2010 and 2100

	(thousands of 2010 US$, market exchange rates)					
	2010		2100			
Transfer limit			*0*	*3%*	*6%*	*10%*
Low-income regions	1.6		6.1	7.3	8.1	9.2
Middle income regions	6.9		25.3	24.3	23.3	21.8
High-income regions	32.8		114.5	108.7	101.1	91.2
Values for 2100 are averages across four climate scenarios (see text)						

As the transfer limit rises, the level of per capita consumption in 2100 declines in both middle-income and high-income regions; in these cases, the middle-income and high-income regions are all contributing the maximum amount to the development of low-income regions. (The sole exception is one 10-percent-limit result in which South Africa, the least affluent middle-income region, is a capital exporter, but sends less than 10 percent of its output to low-income regions.)

[8] In the DICE damage function, the ratio (output net of climate damages/gross output without damages) can be written as $1 / [1 + (T / 18.8)^2]$, where T is temperature increase since 1900 in °C. In the HW damage function, the same ratio is $1 / [1 + (T / 12.2)^2 + (T / 6.24)^{7.02}]$. The seventh-power term in the HW function is insignificant when T is much less than 6.24, but quickly becomes large as T rises above that level.

In fact, the optimal solution under some assumptions includes redistribution among the low-income regions. As shown in Table 1, China and Southeast Asia are much less poor than Africa and South and Central Asia. When resource transfers are limited to 3 percent of output, CRED calls for transfers from China and Southeast Asia (as well as all high- and middle-income regions) to the lowest-income regions. At 6 percent, as increased resources become available from high- and middle-income regions, Southeast Asia becomes a recipient of capital from abroad, while China still exports capital to lower-income regions. At the 10 percent limit, with even greater resources available, China also receives an inflow of capital from abroad. These results occur under all four scenarios, depending solely on the transfer limit.

Although the transfer limits explored here may seem extreme – the 10 percent limit is at least an order of magnitude beyond the magnitude of existing foreign aid programs – the resulting equalization of living standards is comparatively modest. As seen in Table 2, the ratio of high-income to low-income regions' consumption per capita drops only from 20:1 today to 10:1 in 2100 with 10 percent transfers. The difference between zero and 10 percent transfers, for the low-income regions, determines whether they end the century near the top or the bottom of the current range of middle-income regions (see Table 1). For high-income regions, it is the difference between ending the century at 2.4 or 3.0 times greater than current U.S. consumption per capita.

Climate results

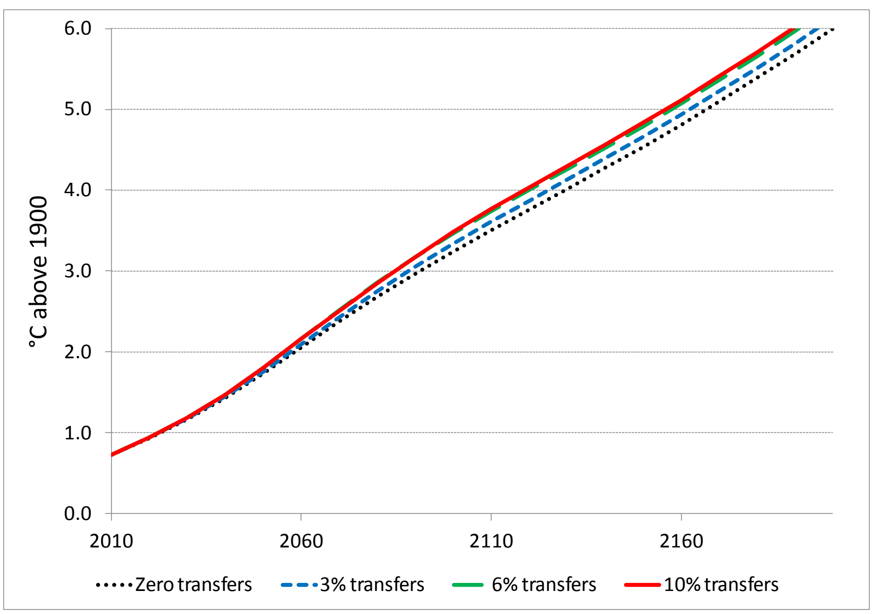

Figure 2. Temperature increase: DICE damages, high discount rate

With DICE damages and a high discount rate – the assumptions that minimize the importance of climate impacts – CRED projects that the climate will never be stabilized, and temperatures will rise steadily throughout the next 200 years (see Figure 2).[9] Emissions from both low and middle income regions rise steadily as well.

In high income regions, emissions drop in the later years of this century and are close to zero in the next century; in these regions, the lower marginal utility of increases in consumption make it worthwhile to trade some consumption growth for climate mitigation. Even with substantial resource transfers, however, low and middle income regions never make that choice, so global emissions and temperatures are never brought under control. The climate results are virtually identical under widely different limits on resource transfers.

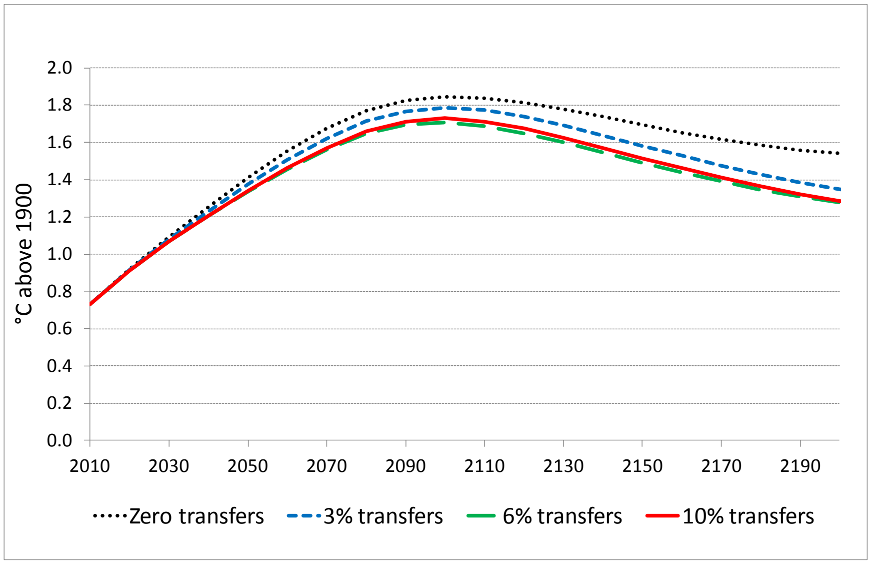

Figure 3. Temperature increase: HW damages, low discount rate

At the opposite extreme, the assumptions of HW damages and a low discount rate maximize climate impacts. Global temperatures peak at 1.7 – 1.8°C in 2100 and then gradually decline (see Figure 3; note the change in the vertical axis scale).[10] The tradeoff between consumption growth and climate mitigation is now tilted strongly toward mitigation; emissions drop to zero by 2100 (the time when complete abatement first becomes possible) in every region, in almost every case.[11] The climate results are again virtually insensitive to changes in resource transfers.

More diverse results appear in the intermediate cases. With HW damages and a high discount rate, the temperature stabilizes in the next century. In this case, the peak temperature is higher and occurs later than in the HW damages/low discount case (see Figure 4). The peak temperature of 2.9°C occurs in 2160 with no transfers, compared to 2.6°C in 2120 with 10 percent transfers.

[9] CRED scenarios are calculated over 300 years; results for the last 100 years are discarded to avoid end effects.
[10] The climate module in CRED v1.4 has been recalibrated to reflect recent research demonstrating that temperatures will not fall significantly for centuries in response to the post-peak decline in carbon dioxide emissions (Stanton et al. 2012). The modest declines seen here result from the reduction in non-CO_2 greenhouse gases.
[11] The one exception: With no resource transfers from other regions, low-income region emissions do not quite reach zero, but average less than 20 percent of the 2010 level throughout the 22nd century.

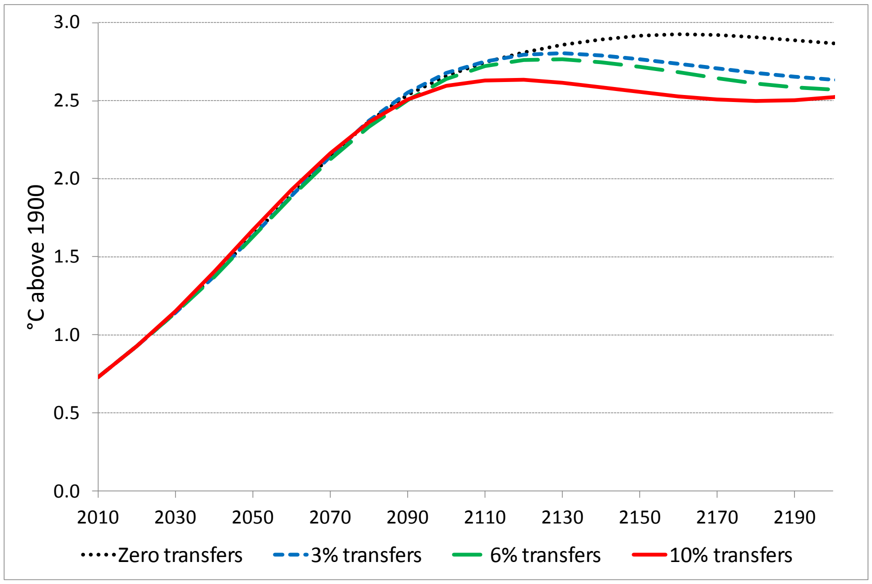

Figure 4. Temperature increase: HW damages, high discount rate

These differences are largely attributable to the pattern of low-income region emissions. High and middle-income region emissions decline to roughly zero by 2100 and remain there, with little variation by transfer level. Low income region emissions, in contrast, never quite go to zero, but are reduced below their 2010 level (see Figure 5). Greater resource transfers lead to lower cumulative emissions in low-income regions, accounting for the improved climate outcomes with higher transfers.

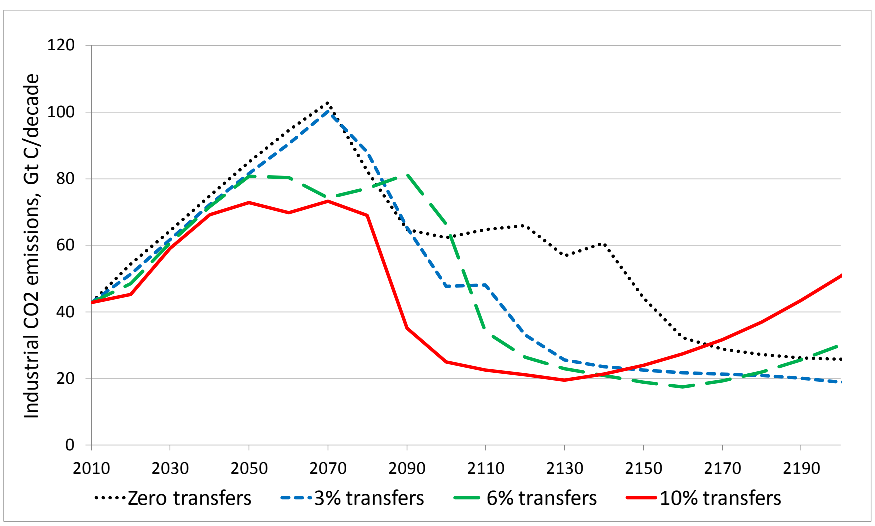

Figure 5. Low-income emissions: HW damages, high discount rate

The effect of resource transfers is more dramatic in the final case, with DICE damages and a low discount rate (see Figure 6). Temperatures are never controlled in the zero and 3 percent cases, rising throughout the 200-year period. In fact, the increase is noticeably faster with 3 percent transfers than with none. With 6 percent or 10 percent transfers, however, the temperature reaches a peak of just under 2.5°C in 2110, and then drifts slightly downward.

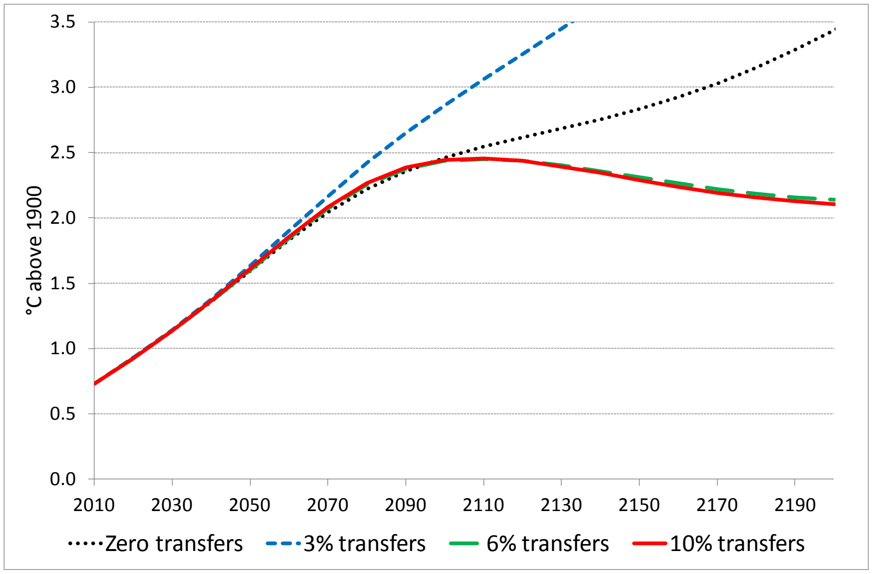

Figure 6. Temperature increase: DICE damages, low discount rate

The differences are again attributable to low-income region emissions. Both high- and middle-income regions reach zero emissions by 2100, and stay there, with little differences by transfer level. Low-income emissions, however, differ sharply by transfer level (see Figure 7). At both zero and 3 percent, emissions rise without limit, driving the similar pattern in temperatures. The additional resources provided to low-income regions with a 3 percent transfer limit are enough to spur more rapid economic growth and emissions, but not to make it worthwhile to curtail emissions.

A threshold occurs between 3 percent and 6 percent transfers: at the higher levels of transfers, low-income regions experience enough income growth to make mitigation attractive to them later in this century. Emissions do not quite reach zero, but remain at one-quarter to one-half of 2010 levels despite rapid economic growth. Additional transfers beyond the threshold lead to greater equality between rich and poor regions, but have almost no effect on emissions and climate outcomes, as shown by the nearly identical results at 6 percent and 10 percent.

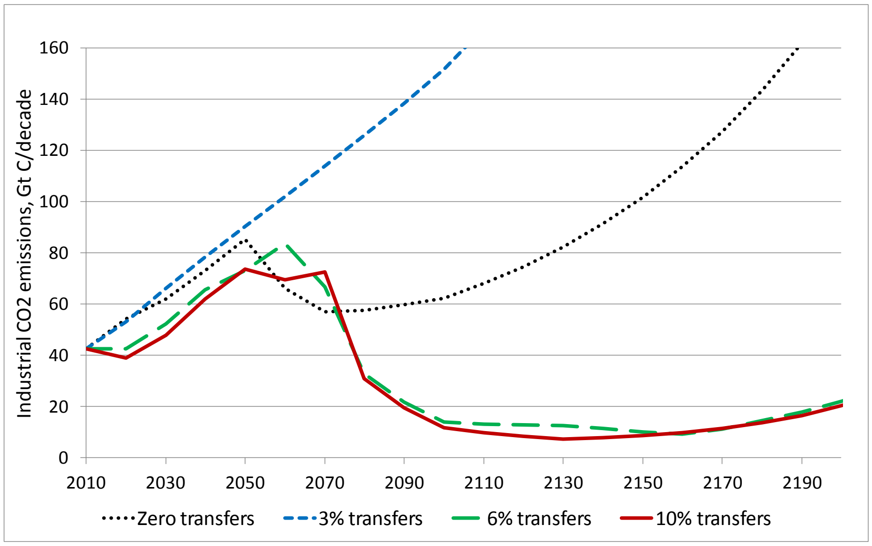

Figure 7. Low-income emissions: DICE damages, low discount rate

Discussion

Our results suggest that the relationship between climate and development policy is not simple or immutable, but rather is contingent on assumptions about the nature and severity of climate risks. At either extreme, the much-discussed link between the two policy domains appears to be attenuated. If the climate problem is assumed to be mild enough that it's not worth doing much about it, then similar policies of near-inaction are appropriate with or without equity and development assistance. This is a perfectly logical deduction, but from an implausible premise.

If, perhaps more plausibly, potential climate damages are assumed to be large enough and the discount rate low enough that the climate threat looms large in present value terms, then the optimal policy is to do a lot about it – again with or without progress on equity and development. In this case, the problem is not with the premise, but with the conclusion. The difficulty arises from the somewhat obscure technical meaning of "optimal policy."

In a model such as CRED, an optimal policy is one that maximizes global utility – a measure of the present value of human welfare, for generations to come. If policymakers in every region act to maximize global utility, and if they all use the same assumptions about climate risks and discount rates, then they will presumably converge on the optimal policy identified by the model. In practice, this convergence could fail to occur for several reasons.

Policy could be narrowly focused on national rather than international outcomes, undermining hopes for cooperation in addressing the thoroughly global climate externality. The elaborate processes of international climate negotiations and related debates over the fairness of alternate solutions are aimed at overcoming this obstacle.

Policy differences could also arise from differing assumptions about climate risks or discount rates. The lowest-income countries, where economic growth and poverty reduction are most urgent, may find it difficult to make decisions focused on the long run, based on the very low discount rates that are often advocated for climate analysis. Resource transfers from higher-income countries may be essential in allowing low-income countries to accept the need for very future-oriented investments – that is, development aid may be essential if climate solutions require everyone to act on the basis of very low discount rates.

Modeling differing national assumptions about climate parameters and discount rates is a challenging analytical task, requiring a computational apparatus far beyond the level of CRED (or most IAMs). It may be instructive, nonetheless, to look at our results for the intermediate scenarios. Under both intermediate cases, we find that the level of development assistance has a significant effect on climate outcomes.

Development is an incremental process, in which a little more is always possible, and is always better than a little less. In contrast, climate policy is subject to thresholds: either we have sufficient collective will and resources to bring emissions down far enough and fast enough stabilize the climate, or we do not. Under intermediate scenario, there is a strongly nonlinear, threshold relationship between resource transfers and climate results: transfers of up to 3 percent of output do nothing for the climate; 6 percent achieves complete climate stabilization; and 10 percent does no more than 6 percent.

The point is not that this set of results should be taken as literal predictions, or 6 percent transfers be taken as a precise requirement. CRED is a simplified model of climate-economy interactions, designed to illuminate underlying relationships rather than to provide detailed plans. Rather, the qualitative message of these quantitative results is worth considering: interactions between climate and development may be crucial at intermediate levels of severity of climate threats, and there may be thresholds requiring significant levels of development assistance to bring the world together in cooperating on climate solutions.

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