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Policy thresholds in mitigation

Katharine L. Ricke, Juan B. Moreno-Cruz, Jacob Schewe, Anders Levermann and Ken Caldeira

Some climate change impacts rise fast with little warming, and then taper off. To avoid diminishing incentives to reduce emissions and inadvertently slipping into a lower-welfare world, mitigation policy needs to be ambitious early on.

Climate impacts are often assumed to increase steadily with global mean temperature for the foreseeable future. However, for a range of systems — such as croplands for staple foods[1], coral reefs[2] or UNESCO world heritage sites that are affected by sea-level rise[3] — impacts are high for relatively modest warming, and then begin to saturate. Indeed, sector-specific simulations of the impacts of climate change on agriculture, ecosystems, freshwater resources, and other parts of the human environment suggest that the scaling of many environmental impacts with temperature approximates a sigmoidal — S-shaped — pattern[1–8] (Fig. 1). For these sectors, the pace of the impact increases drastically at or before 2 °C of warming over a pre-industrial baseline and a large fraction of the impacts is manifested by the point that global temperature reaches this level. Impacts then taper off as warming continues.

Saturation of impacts can occur near physical limits, as when coral reefs are completely destroyed, or in relation to river floods that, however frequent and severe, can only affect so much of a country's total area due to topography. Saturation of impacts can also occur when adaptation partially offsets the impacts of warming. For example, migration towards urban centres can limit the impacts of climate change on the most vulnerable populations by increasing access to amenities such as air conditioning during heat waves[9].

Looking more broadly, four out of five sectors investigated in an intersectoral impact model intercomparison project exhibited a sigmoidal shape[10]. Agriculture[1], biomes[6,7], freshwater[5], and coastal flooding[8] all showed an S-shaped impact distribution with warming, whereas the only study so far that evaluated simulations of malaria risk, the fifth sector, does not allow any statement about the shape of the impact function. These studies are often limited in the range of global temperature changes they use, and therefore have not assessed potential saturation at warming levels higher than 4 °C. Similar nonlinear behaviour may emerge in additional sectors at higher warming levels; and in further sectors for which appropriate numerical models are not available yet.

For sectors, or countries, where climate impacts come early and then begin to saturate, there may be two sets of optimum policies in cost-benefit terms, rather than just one — at different levels of mitigation and thereby environmental and cultural preservation. Essentially, for these sectors or countries, there are strong incentives to limit emissions at low levels of warming, before the bulk of the impacts occurred, but then incentives to mitigate will diminish rapidly. We argue that we need to understand the thresholds between these two economic

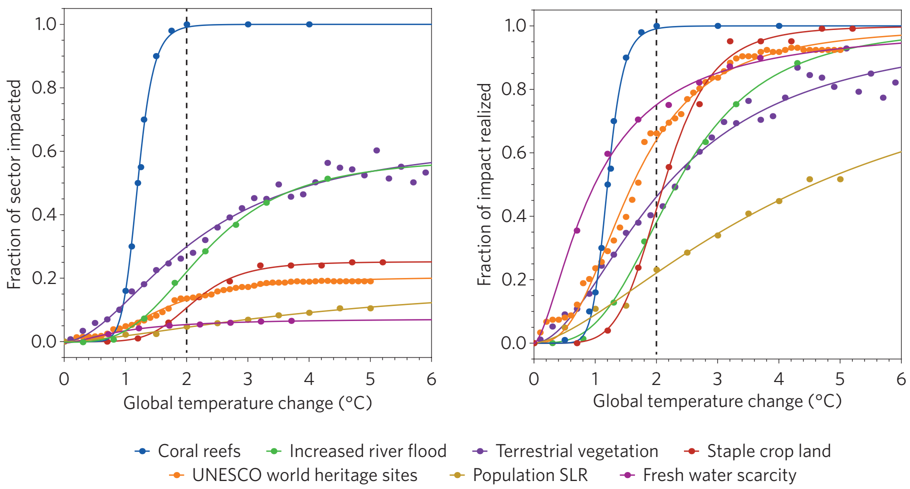

Figure 1 | Climate change impacts for various sectors. For climate impacts such as coral reef degradation[2], river floods[1], changes in terrestrial vegetation[3], yield losses in staple cropland[5], UNESCO world heritage sites in danger from sea-level rise[4], population threatened by sea-level rise[4] and population with scarce access to freshwater[6], impacts rise steeply relative to the total expected impact at low levels of warming and then begin to saturate, usually as a result of either an approach towards the total potential loss or adaptation. The impacts displayed represent the median of an ensemble of simulations; lines are based on a sigmoidal fit. Impacts are normalized by the total sector size (left) and the maximum potential impacts (right) as determined by the sigmoidal fit, ranging from 10 to 100% of the sector for these examples.

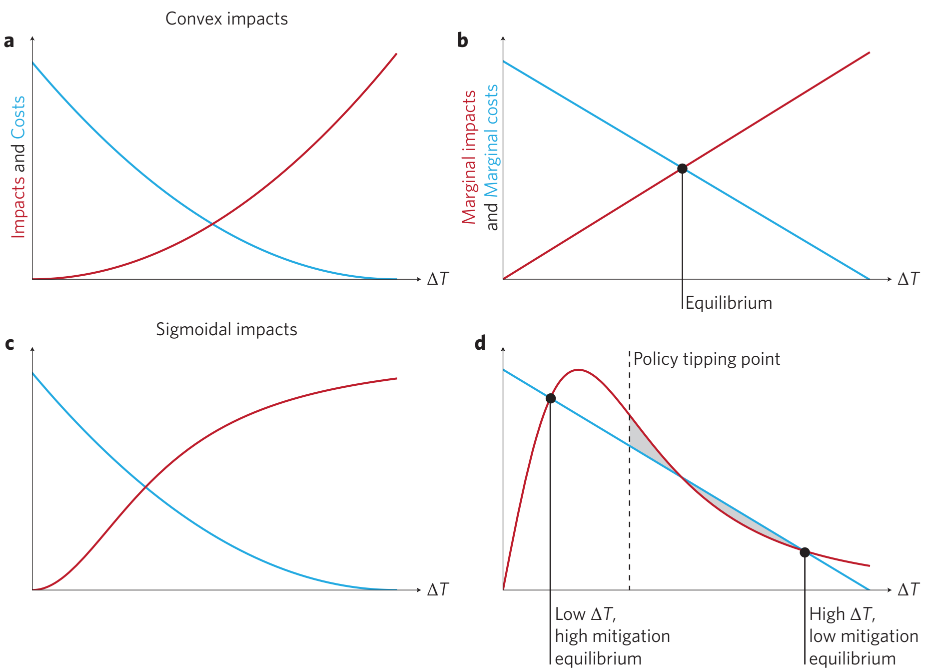

Figure 2 | Policy implications of different scalings of climate change impacts. **a**,**b**, In the canonical model, climate change impacts and mitigation costs are convex (**a**): impacts rise more steeply than linearly with warming, whereas costs of mitigation decline more steeply than linearly. Under these conditions, a single equilibrium point indicates the optimum policy where marginal impacts and marginal costs are equal (**b**). **c**,**d**, If, however, climate impacts are sigmoidal with convex mitigation costs (**c**), multiple policy equilibria can exist, corresponding to different levels of mitigation and therefore, probably, overall welfare (**d**). A policy tipping point marks the level of warming where the low-mitigation temperature target becomes the rational choice.

basins of attraction — the policy tipping point — in order to set appropriate and sufficiently ambitious climate policies.

Policy implications

If enough constituent physical climate impacts exhibit sigmoidal behaviour — that is, their sensitivity to small increases in temperature is highest in the first several degrees of warming — it seems likely that aggregated global economic impacts will exhibit such nonlinear behaviour as well. Societal decision-making with respect to climate change must consider both the economic impacts of climate change, and the costs of avoiding that climate change. Optimal policy design finds a level of mitigation that balances the costs associated with these two sides of the problem (Fig. 2).

The standard assumptions in canonical models of climate change economics have held that the impact function is increasing and strictly convex relative to temperature changes, that is, impacts rise linearly or faster with temperature (at least in the domain relevant for human decision-making). The mitigation cost function is increasing and convex relative to mitigation levels, and therefore decreasing and convex relative to warming (Fig. 2a). Under those assumptions, there is a unique level of mitigation at the intersection of marginal impacts and marginal costs; that is, where one extra dollar of mitigation reduces damages by the same amount. Costs are minimized at this level, and it is associated with a unique value of marginal impacts (Fig. 2b). Optimal climate policy would aim to achieve this equilibrium level of warming. Because marginal impacts continue to rise past this point, if we overshoot the target, the best strategy is still to aim to stabilize temperature as low as still possible. That is, overshooting does not fundamentally change the optimal temperature target, although it would be more costly to achieve this target.

On the other hand, if the impact function is sigmoidal within the range of temperature changes expected in this century (Fig. 2c), the shape of the marginal impact function is substantially different (Fig. 2d). Climate impacts that saturate along the warming trajectory do not necessarily lead to a unique optimum point, but instead they can result in multiple, distinct equilibria[11]. With identical assumptions about the marginal costs of mitigation, the economy can settle in two very different alternative worlds. In one, the mitigation level is low, temperature is high and climate impacts are also very high, but mitigation costs are low. In the other, the level of mitigation is high, temperature is low and climate impacts are also low, but mitigation costs are high.

A policy tipping point (Fig. 2d) can occur before emissions have committed us to a level of warming where the marginal benefits of mitigation still exceed the marginal costs. This hidden transition between two economic basins of attraction has some precedent in both environmental economics[12] and other economic policy contexts[13]. The phenomenon is distinct from physical tipping points[14,15]. There can be a tipping point in the optimal policy aimed at minimizing climate-related costs without a tipping point being passed in the physical system.

With climate change impacts that are severe early on and then taper off, there is a risk that once an optimal global temperature is overshot the world will end up in a state in which marginal costs exceed marginal impacts. These conditions are conducive to a shift in climate goals towards a different equilibrium, characterized by high temperature change and correspondingly low levels of mitigation. If climate policies are not sufficiently ambitious early on, society could land in a state in which welfare is considerably lower than in the low-temperature equilibrium. ❐

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