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The Atmosphere as a Global Commons – Challenges for International Cooperation and Governance

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THE HARVARD PROJECT ON CLIMATE AGREEMENTS

The goal of the Harvard Project on Climate Agreements is to help identify and advance scientifically sound, economically rational, and politically pragmatic public policy options for addressing global climate change. Drawing upon leading thinkers in Argentina, Australia, China, Europe, India, Japan, and the United States, the Project conducts research on policy architecture, key design elements, and institutional dimensions of domestic climate policy and a post-2012 international climate policy regime. The Project is directed by Robert N. Stavins, Albert Pratt Professor of Business and Government, Harvard Kennedy School. For more information, see the Project's website: http://belfercenter.hks.harvard.edu/climate

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The Atmosphere as a Global Commons – Challenges for International Cooperation and Governance[#]

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Abstract: This article analyzes global climate policy as the problem of transforming governance of the atmosphere from an open-access into a global commons regime. This involves several challenges. First, setting an atmospheric stabilization goal requires balancing risks of climate change and risks of mitigation. Second, limiting the atmospheric disposal space for carbon devalues fossil resources and creates a novel climate rent, thus raising distributional issues. Third, policy instrument choice needs to consider the supply side dynamics of global fossil resource markets. Fourth, global climate policy entails strong free-riding incentives. The article reviews incentives for unilateral action and policy instruments as well as alternative conceptualizations of the emissions game that may somewhat alleviate this collective action problem. Finally, the literature on fiscal federalism and fiscal decentralization is considered, promising novel perspectives on designing an efficient decentralized governance regime of the atmospheric commons.

Keywords: Climate Policy, Global Commons, International Cooperation, Fiscal Federalism, Polycentric Governance

1. Introduction

This article analyzes global climate policy as the problem of transforming governance of the atmosphere from an open-access into a global commons regime. Establishing such a regime raises a series of challenges. First, specification of a limit for anthropogenic greenhouse gas disposal in the atmosphere requires balancing the risks of unmitigated climate change with the risks of emission reductions. *Section 2* investigates the difficulty of deriving a globally optimal stabilization target from a cost-benefit analysis and argues that emission reduction policies can be regarded as investments that reduce the likelihood of catastrophic climate change.

Section 3 reviews the literature on optimal policy instrument choice and explores the distributional challenges and options for governing the atmosphere as a global commons. This requires consideration of

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the supply side dynamics in global fossil fuel resource markets and the transformation of the fossil resource rent into a climate rent due to climate policy.

Section 4 discusses the free riding incentives in climate policy and provides an overview of the theoretical work on how these might be reduced. Rationales for unilateral action include co-benefits, cost reductions of low carbon technologies, and signaling in the presence of asymmetric information. The problem of international cooperation might be alleviated when introducing such measures as: international transfers, technology clubs, trade policy, repeated interactions, as well as assumptions about ethics.

Finally, *Section 5* reviews the literature on (vertical) fiscal decentralization and (horizontal) fiscal federalism to investigate additional rationales for unilateral and local climate policy. One key hypothesis is that – under specific circumstances – local emission reduction efforts might facilitate the adoption of globally efficient policy. In this perspective, the effectiveness of local and national policies depends on efficient coordination of policy instruments between different levels of government. Another finding is that under very stylized conditions assuming mobile capital and population a global public good can be provided even in a decentralized governance setting. These findings might offer an interesting starting point for future research on the globally efficient and practically feasible polycentric management of global commons.

2. Climate policy as risk management

2.1 Risks of climate change

The atmosphere is a global common-pool resource in its function as a sink for CO_2 and other greenhouse gases. Currently, it is an unregulated "no man's land" that is openly accessible and appropriated by everyone free of charge in most regions of the world, with the exception of the EU and a select few others that have started to price carbon emissions (see Section 4.2). Oceans, forests and other ecosystems are closely linked to the atmospheric sink and provide services by absorbing a fraction of the anthropogenic CO_2 emissions. In recent years, however, their sink capacity has begun to decline (Canadell et al. 2007). Congesting the atmosphere with greenhouse gas (GHG) emissions leads to dangerous and potentially catastrophic climate change. Further increases of global mean temperature may trigger irreversible tipping elements in the earth system. These include melting of the Greenland Ice Shield (GIS) over several centuries as well as melting of the West Antarctic Ice Shield (WAIS), each containing enough ice to raise the global sea-level by several meters (maximally 7m from GIS, and 3m from WAIS). Further, melting of the Siberian permafrost will lead to the release of methane, a potent GHG, and thus accelerate global warming. Other tipping elements include the breakdown of the thermohaline circulation in the northern Atlantic triggering a drop in average temperatures in Europe, and a complete drying of the amazon rainforest. Notably, tipping of any of these elements may severely damage or destroy the habitats mankind has populated since the Holocene epoch. The precise threshold values – less than 1.5°C, 2°C, 3°C or more – at which these and other tipping elements are triggered are subject to substantial uncertainty (Lenton et al. 2008). There are indicators that a disintegration process of parts of the WAIS implying 1.5m sea-level rise has already been initiated (Levermann 2012). Notwithstanding these uncertainties concerning the precise threshold values of tipping elements, a recent assessment of impacts concludes that a rising global mean temperature would affect the frequency and intensity of extreme weather and climate events (IPCC 2012).

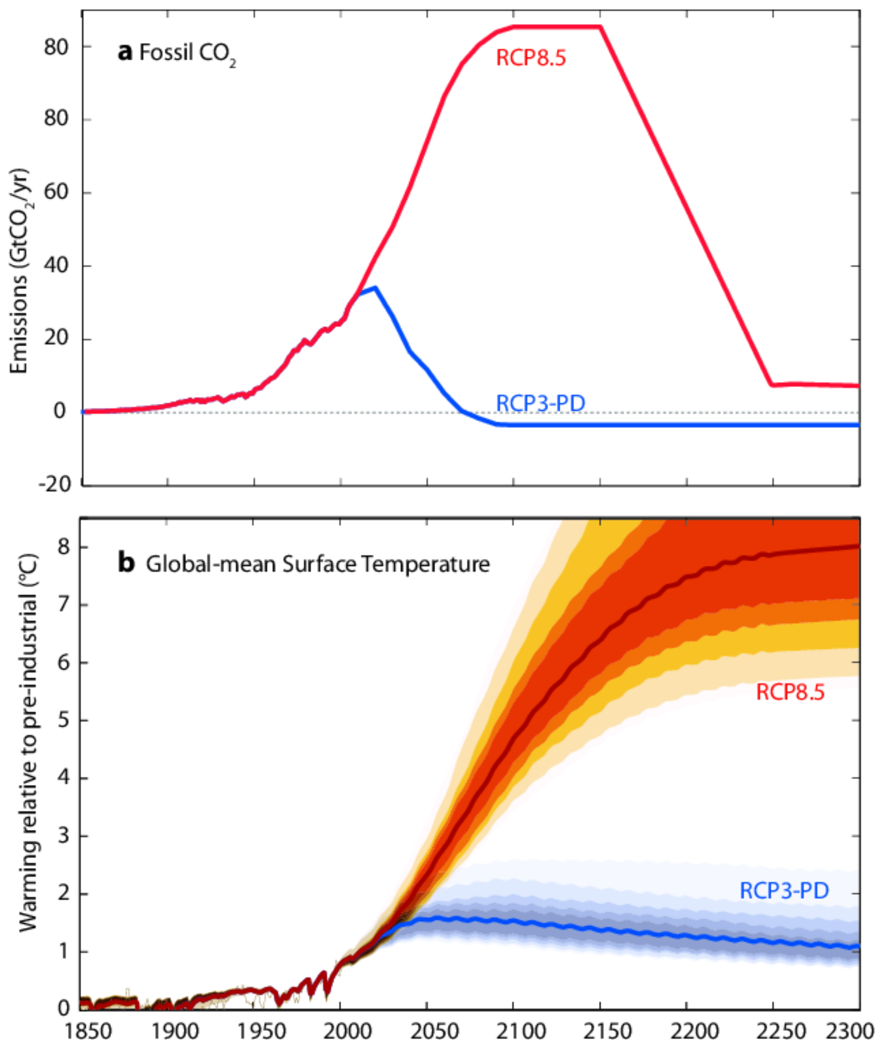

Figure 1: (a) Two anthropogenic CO2 emission pathways (RCP8.5 and RCP3), and (b) global warming relative to pre-industrial level associated with these pathways expressed in probabilistic terms. Source: Adapted from Fig. 3 and Fig. 6 in Meinshausen et al. (2011).

In addition to the uncertainty over impacts, there is uncertainty regarding the climate system response in terms of warming for a given level of atmospheric GHG concentration (climate sensitivity). Given the unprecedented character of the experiment mankind is currently conducting with the earth system, values for this parameter need to be derived from a combination of historical data and climate modeling. Meinshausen et al. (2009) apply a probabilistic analysis to scenario data obtained from climate modeling that takes into account the uncertainty over the warming triggered by a certain increase of the atmospheric greenhouse gas concentration. Their analysis indicates that a doubling of the atmospheric concentration of CO_2 corresponds to global warming of 2.3-4.5°C within the 68% confidence interval, and 2.1-7.1°C in the 90% confidence interval. This leaves open the possibility of surprises of even higher as well as lower climate sensitivity. Clearly, warming of 7°C or more within one century will impose severe impacts on human societies and the global economy.

Figure 1a-b shows two global emission scenarios and an assessment of concomitant global warming levels based on a probabilistic analysis of existing global warming models. The simulations are based on the so-called 'Representative Concentration Pathways' (RCPs) (Meinshausen et al. 2011). RCP8.5 can be regarded as a business-as-usual emission scenario leading to a radiative forcing (i.e the balance of incoming and outgoing energy of planet earth) of 8.5 W/m^2 in year 2100. Emissions are assumed to peak between 2100 and 2150 and decline thereafter. Figure 1b shows that there is a probability of at least 50% of global warming exceeding 6°C by 2150 in this scenario, rising steeply thereafter (the mean temperature increase is denoted by the solid red line in Figure 1b). By contrast, reducing emissions as indicated by the RCP3-PD scenarios (radiative forcing peaking at 3 W/m^2) would provide considerable certainty of avoiding warming above 2°C. However, this scenario would require constant *net negative* global emissions after the year 2075. This requires a major global mitigation effort. Net negative global emissions could potentially be achieved by using biomass – with plants absorbing CO_2 from the atmosphere – in combination with carbon capture and sequestration (CCS) technology that separates CO_2 contained in the biomass to store it underground.

2.2 Risks of mitigation

Some observers argue that limited supplies of coal, oil, and gas will soon lead to increasing resource prices, which will induce a rapid switch to renewable energy sources and increased energy efficiency even if the climate benefits of these technologies are not taken into account (e.g. UNEP 2011). That is, they hope that green technologies can offer a means to foster rather than reduce economic growth, and yield environmental benefits at the same time.

This assertion, however, is likely to be an illusion. Up to 15.000 Gigatons (Gt) of CO_2 are still stored underground, mostly in the form of coal, which can be used for generating electricity and even to produce transport fuels via coal-to-liquid processes (IPCC 2011).

For those proposing ambitious atmospheric stabilization goals, hoping for a rapid autonomous cost decrease of renewables is a dangerous gamble since this expectation might deter further climate policy efforts. Renewables have indeed experienced large cost reductions in recent years, but their share in meeting global primary energy consumption is only about 13 %, with half of that coming from traditional biomass, such as wood, charcoal, or animal dung (IPCC 2011). Prices for fossil energy sources will rise at some point and costs of renewables will decrease. Thus, the question is: will this structural change come about in time to prevent a significant rise in global mean temperature? The answer from almost all scenario calculations reviewed in the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (IPCC 2011) is: no. In fact, instead of decarbonization and a decline of emissions, the world energy system is currently experiencing a renaissance of coal leading to steeply rising CO_2 emissions, particularly due to rapid economic growth in China (Raupach et al. 2007, Steckel et al. 2011).

Emission scenarios for the 21st century generated by large-scale numerical economy-energy-climate models indicate that limiting global warming to 2°C with 100% certainty is highly challenging, if not practically impossible, by this point in time. Cumulated emissions of 1,300Gt CO_2 have already been emitted since 1850 (WRI 2012), leaving little space for future atmospheric emission disposals if the ambitious 2°C goal is to be observed. Even attaining the 2°C goal with significant probability is highly challenging when considering that global net negative emissions are likely to be required by the end of this century (see Figure 1).

What are the economic costs of meeting specific ‘carbon budgets’, i.e. limits to cumulative emission disposal in the atmosphere until the year 2050? Figure 2 summarizes the cost estimates from scenario calculations of the globally available climate-energy-economy models. They indicate that – assuming a cost-efficient transformation of the global energy system – the loss in gross world product could be limited to a few percentage points. The costs of restricting atmospheric usage typically rise with the level of ambition. Only one model (E3MG) finds a negative relationship between the level of climate policy

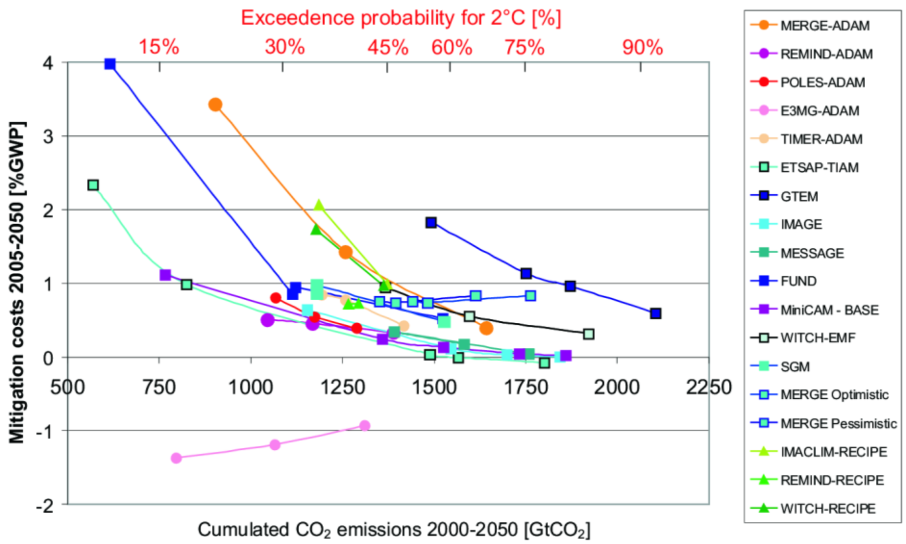

Figure 2: Mitigation costs rise with level of ambition. Overview of model results on macroeconomic costs of mitigation in terms of gross world product (GWP) losses or cumulative abatement costs (as area under marginal abatement cost curve) relative to baseline GWP (in %) for 2005–2050 in dependence of the cumulated fossil fuel CO2 emissions from 2000 to 2050 (discounted at 5% discount rate). Results are reported for several models and model intercomparison projects, and include only fully efficient scenarios (all technologies available, globally harmonized climate policy). Source: Knopf et al. (2011)

ambition and costs, which is due to the Keynesian structure of the model where exogenous investment shocks reduce existing distortions and thus enhance welfare.

Yet these scenarios assume full availability of a range of technologies and globally efficient climate policy, i.e. a harmonized global carbon price. Clearly, these are rather optimistic assumptions. For instance, some technologies might be used on a smaller scale than projected by the models either because technological progress turns out to be slower than expected, or due to a lack of social acceptance. This latter point could be of particular relevance for nuclear power, CCS, and biomass use (which is likely to have an impact on food prices due to competing use of arable land). Three recent model comparisons have highlighted that for all models under study, low availability of renewable energy technologies and foregoing the use of CCS – particularly in combination with biomass –substantially raises mitigation costs (Edenhofer et al. 2010, Luderer et al. 2009, Clarke et al. 2009) and make ambitious stabilization at a low atmospheric concentration of greenhouse gases (400ppm CO_2-eq.) impossible to achieve for the models (Edenhofer et al. 2010). On the other hand, the model calculations also indicate that restricting the use of nuclear power to its baseline level i.e. the one that would prevail without climate policy (Luderer et al. 2009) or even a global nuclear phase-out (Edenhofer et al. 2010, Bauer et al. 2012) would hardly increase mitigation costs, if alternative technologies such as renewables and CCS are available.

Moreover, the costs of achieving a given climate target will also rise if the adoption of a global climate agreement is delayed or only a sub-set of countries participate in such an effort from the onset. The already existing energy and transport infrastructures are estimated to account for a commitment of almost 500 billion tons of CO_2 over the next fifty years (Davis et al. 2011). Without climate policy, additional carbon-intensive infrastructure will be built up in the near future, which due to this infrastructure's lifetime of several decades, would result in a lock-in of the associated emissions (Jakob et al. 2012). Hence, if the adoption of climate policy is delayed until the year 2020 with all countries following their current business-as-usual emission pathways, global mitigation costs are projected to increase by at least half. Further, a delay of climate policy until the year 2030 renders a stabilization target of medium ambition (450ppm-CO_2-only) impossible to compute in several models (Luderer et al. 2009).

2.3 Choosing a global stabilization target

As the preceding sections have shown, choosing a global stabilization target involves a trade-off between reducing the risk of anthropogenic climate change and increasing the costs of mitigation. An often employed tool to perform an economic valuation of this kind of problem is cost-benefit-analysis (CBA), which aims at determining the abatement level which maximizes the difference between the benefits from avoided climate damage and the associated mitigation costs. Pursuing this technique, different authors have come up with estimates of socially optimal carbon prices that differ by an order of magnitude, ranging from about 10$ per ton of CO_2 (Nordhaus 2007) to 100$ per ton of CO_2 (Stern 2007).

Detailed analysis of these divergent results reveals that – as the large brunt of climate damages are likely to manifest themselves in the far future – the optimal carbon price depends crucially on the discount rate that is employed to convert future damages into net present values (Weitzman 2007). While Nordhaus (2007) uses a discount rate of 5% derived from observed market transactions, Stern (2007) applies a considerably lower rate of 1.4%, arguing that it represents first and foremost an ethical choice regarding the welfare of future generations that cannot be derived from market outcomes. This latter argument receives support by the point that in contrast to the assumption of infinitely lived representative agents incorporated in models commonly used to study the economic implications of climate policy a model with overlapping generations that are only mildly altruistic might provide a more realistic description of the relevant trade-offs between foregoing current consumption and preventing future damages. In such a setting, there is no reason to expect that market interactions will yield the outcome that would seem mandated from an ethical perspective. In particular, a utilitarian social planner would employ a strictly lower discount rate than private agents to compare current costs with future benefits (Schneider et al. 2012).

The task of choosing a stabilization target is made even more difficult when uncertainty is taken into account. For instance, future increases of total factor productivity, and hence consumption growth, are impossible to predict with certainty. It is well known that future consumption growth has an important influence on the discount rate; the wealthier people are in the future, the less they will value any additional unit of consumption and the higher hence the discount rate. Consequently, with uncertain long-term growth prospects, policy makers are confronted with a wide array of possible discount rates. In this situation the optimal discount rate displays a declining term structure i.e. the discount rate should be the lower depending on how far a project's payoff lies in the future. This is due to the fact that in the calculation of the (weighted) average over possible discount factors (which are convex functions of discount rates) to derive an expected discount factor, lower discount rates receive higher weights in the long term than in the short term (Freeman 2010, Gollier and Weitzman 2010).

In addition, the standard cost-benefit approach faces serious difficulties when considering low probability climate impacts that may yield catastrophic impacts *and if such destruction is to be avoided by all means* (Weitzman 2009). Even though the question how to ascribe an economic value to catastrophic impacts raises serious ethical as well as empirical challenges (Millner 2013), the rationale for such a precautionary approach appears pervasive in the climate change context due to the large-scale and indeed planetary stakes. According to Weitzman (2009), if the precautionary principle is applied the marginal damage of a ton of CO_2 may rise to infinity and hence cannot be weighed against the marginal costs of mitigation.

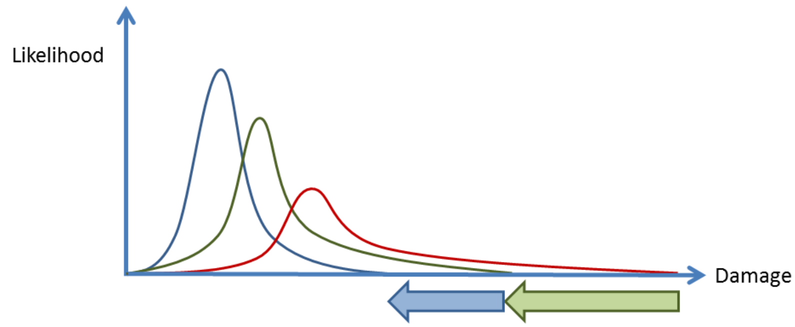

Figure 3: Climate policy can be regarded as reducing the probability of catastrophic climate change: A more stringent global carbon budget – as indicated by green and blues arrows and the corresponding probability density functions – reduces the risk of catastrophic damage.

Even though this so-called 'dismal theorem' only identifies marginal effects, it has been demonstrated to apply also for a non-marginal analysis in cases in which current consumption can – as an insurance against catastrophic impacts – be transferred to the future only with uncertainty (Millner 2013). As uncertainty about climate damages seems likely to affect also inter-temporal transfers, this assumption seems realistic. From the point of view of the precautionary principle, then, climate change should be mitigated to a level that minimizes the risk of irreversible and potentially infinite damages.

Figure 3 summarizes this rationale in a highly stylized manner. The horizontal axis indicates the magnitude of damages from climate change, while the vertical axis denotes probability. Restricting the carbon budget relative to BAU tilts the aggregate probability density function – combining uncertainty about climate sensitivity and damages – and its "fat tail" to the left. In this framework, a more ambitious stabilization target can be regarded as an option to reduce the probability of catastrophic climate impacts. As new information on climate impacts or mitigation costs and risks will become available in the future, climate stabilization goals may be revised.

While formally deriving decision criteria on the optimal level of abatement in such an alternative framework remains a theoretical challenge that inevitably raises important value questions, it seems convincing to consider mitigation policy as an investment to reducing the probability of catastrophic climate change. Even if the future should reveal that dangerous climate change is less likely than feared, and the costs of mitigation higher than hoped, it is rational to invest into avoiding existential risk given the best available knowledge today. For this reason, the international community's agreement at Copenhagen (in 2009) and Cancún (in 2010) to limit global warming to 2°C above the pre-industrial level should probably best be regarded as an attempt to reduce the risk of triggering the earth system's 'tipping-elements' (cf. Section 2.1), while at the same time keeping mitigation costs under control in order to minimize risks to prosperity and human well-being, rather than the outcome of a cost-benefit analysis.

Even if the global community agrees on a global stabilization goal such as 2°C and a corresponding global carbon budget, there are three major additional problems that must be overcome. First, appropriate policies to incentivize emission reduction are needed for implementation at national and subnational levels. Second, defining the scarcity of the atmospheric disposal space creates a novel climate rent and reduces the rents of fossil resource owners, thus raising distributional issues. Third, limiting the use of the atmosphere involves a collective action problem. These challenges are discussed in the following sections.

3. Governing the atmospheric commons

While the atmosphere meets the descriptive criterion of a *common pool resource* as exclusion from usage is costly and usage of sink capacity is subtractive, it is currently clearly not governed as a 'commons', i.e. there is no *common property regime* in place. Instead, in most world regions the atmosphere is de facto a 'res nullius' with open access to anyone wishing to deposit carbon or other GHGs. One option to manage the atmosphere is to declare it a common property of mankind and regulate accordingly. The following subsections analyze the climate problem as a problem of governing such a global commons and investigate options for implementing policy instruments (3.1) as well as the inescapable distributional issues (3.2).

3.1 Policy instruments and supply side dynamics

The optimal policy to deal with a global environmental problem recommended by economic theory requires a globally uniform price equal to the marginal damage caused by the pollution (Baumol and Oates 1975). This can either be achieved by taxing greenhouse-gas emissions, or by limiting the total amount that can be emitted by a cap and introducing tradable emission permits.

While both approaches are fully equivalent in the deterministic case, they display important differences in the presence of uncertainty. As pointed out by Weitzmann (1974) in a static setting, the choice of an optimal instrument crucially depends on the slopes of the functions describing the marginal benefits of avoided emissions and the marginal costs of abatement. Based on this reasoning, a flat marginal benefit function would mandate a tax policy, while with a flat cost function a quantity instrument should be preferred. As carbon emissions have a relatively long atmospheric lifetime (Archer et al. 2009) they can be regarded as a 'stock pollutant'. Emissions in a single year or even decade have only a minor impact on the total amount of greenhouse gases in the atmosphere, such that the marginal benefit function can be considered to be rather flat in this temporal perspective (Pizer 1999). However, a more careful analysis reveals that for a dynamic problem, possible serial correlation of mitigation costs also plays a crucial role (Newell and Pizer 2003, Karp and Zhang 2005). That is, if changes in the marginal abatement cost structure are not only transitory but also persistent (e.g. due to a slowdown in the technological progress of low-carbon technologies, which leads to higher mitigation costs not only in the current time period, but also in future ones) the main advantage of a tax – namely to smooth costs by performing more (less) abatement in periods with lower (higher) costs – is severely reduced.

Taking these caveats into account, the respective literature has found that for a wide range of realistic parameter values a price instrument (i.e. a carbon tax) should be preferred to a quantity instrument (i.e. emissions trading) if the time-path of the respective future policy is to be specified ex ante (Newell and Pizer 2003, Karp and Zhang 2005). However, introducing banking and borrowing of emission permits across trading periods provides greater flexibility for firms to react to higher (lower) costs in any single period by abating less (more) emissions, thus smoothing abatement costs over time and also reducing the costs of complying with a given climate target (Rubin 1996). Given a correctly specified 'trading ratio' at which emission permits originally issued for one trading period can be transferred to another one, emissions trading with banking and borrowing results in the socially optimal distribution of emissions over time even in the presence of uncertainty (Leiby and Rubin 2001).

A further distinction between price and quantity instruments to put a price on emissions arises when taking into account the supply side of fossil fuels, or, more precisely, the resource suppliers' strategic reaction to climate policies (Kalkuhl and Edenhofer *in press*). That is, putting a tax on the use of fossil fuels that rises over time could in effect accelerate global warming, as resource owners anticipate higher future taxes and increase near-term extraction, even if these taxes are implemented globally to cover all countries (Sinn 2008). This 'green paradox' has been shown to arise only under some specific conditions (i.e. if the carbon tax rises at a rate that exceeds the effective discount rate of the resource owners), and assumes that the regulator implements and commits to a permanently mal-adjusted tax (Edenhofer and Kalkuhl 2011). Nevertheless, the possibility of strategic resource supply side reactions in conjunction with the regulator's informational requirement of setting the right tax (which would vary across resource owners as a function of their cumulative past extraction) and credibly committing to its policy schedule might mandate against a purely price-based regulation. The efficiency of a carbon trading scheme with banking and borrowing, however, depends on the availability of complete and efficient future commodities market which is a rather strong assumption (Edenhofer and Kalkuhl *in press*).

It should be noted that the choice between a price and a quantity instrument is not necessarily an exclusive decision for or against one of these policy instruments. In this vein, so-called 'hybrid approaches' that combine price- and quantity-targets have been proposed (see Pizer 2002, and Newell et al. 2005). These include e.g. price-corridors to establish a 'safety valve' against excessive price volatility by increasing (decreasing) the supply of permits if their price reaches a previously specified upper (lower) bound (Burtraw et al. 2009a).

Besides the environmental externality arising from the emission of greenhouse gases, the development of novel low-carbon technologies has been identified as an additional source of market failure in mitigation policy (Jaffe et al. 2005). From this perspective, the fact that the inventor is unable to fully appropriate the associated social benefits of a new technology results in their under-provision, hence mandating subsidies for technology development and deployment (Newell et al. 2006). While such technology market failures are wide-spread across the entire economy and not restricted to 'green' technologies, they can be considered to be of special importance for the case of energy technologies. As highlighted by Kalkuhl et al. (2013), with a high degree of substitutability between fossil energy sources and low-carbon technologies in combination with potential future cost reductions by means of learning-by-doing for the latter, even small market imperfections can result in a 'lock-in' in which the wide-spread adoption of the socially desirable technology option is delayed by several decades. Consequently, the optimal policy to address climate change is considered to include a portfolio of instruments targeted at emissions, learning-by-doing, as well as research and development (Fischer and Newell 2008).

Obviously, it would also be conceivable to conduct climate policy without directly putting a price on carbon (for instance if this is impossible due to political constraints). Handing out subsidies to renewable energy sources that are high enough to render the latter competitive with fossil fuels would be such a 'second-best' policy. Yet, by lowering the price of energy, this approach can be expected to significantly increase energy consumption and thus increase the costs of reaching a given climate target, at least in the long run. For transitory periods followed by carbon pricing in the not too distant future, renewable subsidies may be an intermediate 'second-best' substitute to carbon pricing (Kalkuhl et al. 2013). For this reason, policies that avoid emissions without reducing fossil fuel demand (which would lead to lower energy prices) – such as subsidies for carbon capture and sequestration – are likely to carry the lowest costs in the presence of imperfect or missing carbon prices (Kalkuhl et al. 2012).

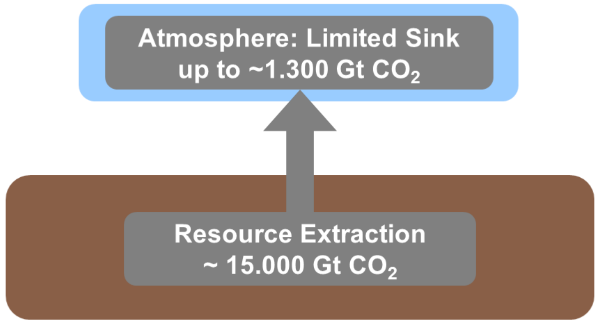

Figure 4: With an ambitious climate policy goal the atmospheric sink constraint is tighter than the constraint from fossil resource scarcity.

In addition to cost-efficiency considerations, the distributional impacts of climate policies are an issue of primordial importance for policy makers – at least in a realistic setting in which transfers to compensate those that bear over-proportional losses are unavailable. Some studies find regressive effects of carbon pricing, due to the fact that poorer households spend a larger share of their income on energy-intensive goods (e.g. Grainger and Kolstad 2010), while others highlight that if associated changes in wages and returns to capital are properly taken into account, the effects of such policies might in fact be progressive (e.g. Rausch et al. 2010). In any case, the distributional effect of carbon pricing will crucially depend on how revenues from a carbon tax or auctioned permits will be employed e.g. to lower taxes on labor income (Burtraw et al. 2009b). Besides households, firms will also be affected by climate policies. That is, highly carbon-intensive activities are likely to be most severely impacted by a price on carbon, while less carbon-intensive ones could even increase their market share (Pahle et al. 2012). As a consequence, these distributional effects can provide incentives to engage in lobbying in order to strategically influence the formulation of climate policy (Habla and Winkler *in press*). Finally, climate policy does not only entail distributional effects within individual countries, but also between countries. This aspect is discussed in the following subsection.

3.2 Allocating the climate rent

Pricing carbon dioxide emissions to limit the use of the atmospheric sink has significant economic implications: in effect, novel atmospheric property rights are created and become subject to a distributional process. In a world without climate protection, everybody can use the atmosphere for free. With a binding limit such as a global carbon budget the disposal space is restricted and a novel scarcity rent, the “climate rent”, is created. In a global emissions trading system, the net present value (NPV) of the total climate rent is equal to the intertemporal budget of emission permits times the carbon price. Equivalently, with a global carbon tax scheme ensuring compliance with a corresponding budget, the climate rent is equal to the cumulated NPV of the carbon tax revenue over time.

Transformation of fossil resource rent into climate rent

In addition to creating a climate rent, restricting the use of the atmosphere as a carbon sink devalues the property titles of the owners of coal, oil and gas. Particularly coal extracted and deposited into the atmosphere in the business-as-usual scenario needs to remain underground in case of ambitious global climate policy (IPCC 2011). At the same time, restricting global demand for fossil fuels is conceptually equivalent to exerting market power on the international fossil resource market, thus lowering world fossil resource prices and reducing the scarcity rent of fossil resource owners (Leimbach et al. 2010).

Both effects combined imply shifting rents from fossil resource owners to the novel owners of the climate rent, with the latter needing yet to be defined (Kalkuhl and Edenhofer *in press*). This economic mechanism explains resistance against ambitious and uncompensated climate policy by fossil resource owners. It also indicates why international negotiations over regional emission reduction goals, which are equivalent to the allocation of valuable regional carbon budgets, are so contended.

From a libertarian perspective or from the point of view of the affected fossil resource owners, the following ethical argument against the legitimacy of these distributional effects of climate policy may be put forward: insofar as climate policy expropriates the owners of fossil resources, it can be regarded as an illegitimate attack against the institution of private property. This argument then requires showing why such 'expropriation' might be ethically legitimate. We briefly consider four arguments.

First, it may be argued that climate policy does not lead to a redistribution of property titles in resource stocks, but only to a change in their value. Such changes in the value of property induced by policy or technological progress have occurred throughout history. Protection of property titles as such need not imply protecting their market values. On the other hand, setting a limit on global carbon extraction implies that not all fossil resource titles can be put to market use (unless CCS is adopted), so some element of expropriation appears to prevail. Further, claims for compensating 'regulatory takings' (devaluation of assets due to public policy) are not uncommon (Miceli and Segerson 2007). Second, even if fossil resource devaluation is considered genuine expropriation, the institution of 'eminent domain' may be invoked, which justifies expropriation if it serves the public good - in this case a reduction of catastrophic climate risk. Eminent domain usually requires compensating expropriated value, which raises the question if fossil resource owners should be financially compensated under climate policy. Indeed, fossil resource rich countries in UNFCCC negotiations have demanded this (Depledge 2008, Mouawad and Revkin 2009). A third and related argument draws on the principle of the 'social obligation of private property'. This argument goes back to Aquinas (1265–1274; see also Chroust and Affeldt 1951) and holds that the institution of private property in natural resource endowments is ethically justified only if it serves the common good more than the primordial concept of common property.

Summing up it may be argued that even while the final verdict on the debate over compensatory claims of fossil resource owners will inevitably be subject to political negotiations, a rational exchange of ethical arguments pertaining the legitimacy of such claims is both feasible and useful to inform political negotiations, especially if questions of the legitimacy beyond pure power politics are to play a role.

Distributing the climate rent

Deliberately creating a climate rent by limiting atmospheric usage via carbon pricing raises the question of how to distribute this rent. As international climate policy negotiations over regional emission reduction goals imply the distribution of regional climate rent endowments, a major and so far perhaps underappreciated challenge of climate policy negotiations is to deal with what may be largest distributional negotiations the global community has ever engaged in.

To illustrate the orders of magnitude, consider a simple back-of-the envelope calculation: With 33 billion tons global CO_2 emissions in the year 2010 (CDIAC 2012), the potential global climate rent was 330 bn € assuming a carbon price of 10\$/tCO_2 this year, or 1.65 trillion \$ assuming a carbon price of 50\$/tCO_2

(omitting that such a carbon price would lower emissions for the sake of simplicity). With a global GDP of 77 trillion $ in 2010 (CIA World Factbook 2012), the latter climate rent volume implies 2% of global GDP being put on the UNFCCC negotiation table.

For identifying key conceptual issues, let us assume the global implementation of an ambitious carbon budget e.g. associated with the 2°C stabilization target by means of a global cap-and-trade scheme where permits (the value of which represents the climate rent) are freely tradable. Additionally, we assume separability of permit allocation and efficiency. In such a stylized setting, the question of permit and concomitant rent distribution boils down to a zero-sum game (WBGU 2009; Luderer et al. 2012). Different ethical proposals to address this distributional problem – usually framed in the context of allocating emission permits among countries or individuals – have been advanced. We briefly inspect three major approaches in this debate.

The so-called *grandfathering* rule foresees distribution of permits in proportion to countries' current emissions or GDP. It might be justified on libertarian grounds by arguing that current emission levels represent a legitimate property title constituted by an 'atmospheric taking', or simply by invoking custom and practice. Grandfathering of emissions is the starting point for proposals by developed countries such as the United States and Europe, combined with the offer to reduce the initial endowment over time. Caney (2009) states that no moral or political philosopher defends a pure grandfathering principle for emission permit distribution, as it is both insensitive to the legitimate needs and rights of non-emitters (usually poorer individuals and countries) and the concept of historical responsibility. This does not exclude the ethical argument to accept a grandfathering rule if it facilitates the adoption of a global climate policy that will reduce climate impacts and large-scale risks. Still, he argues that such acceptance does not render the grandfathering rule ethically convincing as such.

The proposal of distributing the climate rent according to *historical emissions* has in particular been put forward by developing countries (see most notably Brazil 1997). It frames the atmosphere as a common-pool sink with finite capacity and distributes equal-per-capita ownership rights over time, e.g. since 1850. As developed countries have emitted relatively more in the past, their remaining endowments shall be lower than those of developing countries. The claim of historical responsibility of industrialized countries appears convincing at first glance. However on closer examination there are two key problems. First, people living today and in the future can hardly be directly held responsible for the past activities (e. g. emissions) of their ancestors. Second, earlier generations cannot be held responsible as they did and could not know about the harmful consequences of emissions. On the other hand, some argue that historical emissions are relevant for permit allocations insofar as citizens in developed countries today benefit from the significant capital stocks that have been accumulated using carbon emissions (Meyer and Roser 2006).

Finally, the remaining carbon budget may be distributed according to an equal-per-capita rule. This principle may be derived from the theory suggested by Aquinas (1265–1274), who argues that the primordial ownership structure for natural endowments is communal, with legitimate private property titles (e.g. emission permits) being introduced for efficiency reasons. The equal-per-capita rule also resonates with Locke (2003[1689]) and subsequently Nozick (1974) who argue that unequal initial appropriation of natural resources is only legitimate if there is "…enough, and as good, left in common for others." This is clearly not the case with scarce emission permits, and thus an equal distribution of these endowments might constitute a more convincing approach.

An alternative perspective on concepts for distributing the climate rent is to consider the regional (or perhaps even individual) economic cost of attaining a certain stabilization goal and then consider the merits of different permit allocations in achieving an ethically convincing final distribution of the aggregate global costs of mitigation (Rose et al. 1998). Conceptually, in a comprehensive and efficient global carbon trading scheme and assuming perfect information on regional mitigation costs, any distribution of mitigation costs can be achieved using appropriate permit allocations. Those who value the ability to emit relatively highly - e.g. because they have a carbon-intensive industrial infrastructure - will purchase permits from those who value them less, thus leading to financial transfers. In fact, in this perspective the equal per capita distribution may be considered less convincing as it can lead to windfall profits from mitigation policy in developing countries (e.g. Knopf et al. 2012). While such net transfers to developing countries may be considered desirable though a global equity perspective, a more intuitive – and politically realistic – rule may resort to a two-step argument: First, there could be a principle of 'no negative costs', i.e. no region derives net profits from mitigation policy, and second, total global mitigation costs could be shared according to a progressive 'ability to pay' burden-sharing rule, reminiscent of standard UN arrangements for financing UN-operations and peacekeeping missions (Barrett 2007). Such an approach would also resonate with the UNFCCC principle of sharing mitigation costs according to 'common but differentiated responsibilities and respective capabilities' (UNFCCC 1992, Article 3.1).

The major conceptual problem of the cost-sharing approach is that the global and regional distribution of mitigation costs and permit prices which determine the value of international financial transfers in a permit trading scheme are uncertain. Also, a thorough adoption of this line of argument requires evaluating the costs of complementary climate policies such as technology support schemes, which raise significant complexities in monitoring and evaluating the costs of regional mitigation efforts. Nevertheless, it seems convincing that this outcome-based perspective should complement the negotiations over regional emission budgets and the initial allocation of climate rents.

While naturally the distributional debate can only be resolved in political negotiations, the arguments briefly outlined here shall illustrate that the rational exchange of arguments pertaining the ethical legitimacy of distributional rules for sharing the global climate rent may be useful to inform political negotiations, and that scientific and philosophical analysis can contribute productively to this discourse.

4. The challenge of global cooperation

Efficient governance of the atmosphere requires global cooperation and coordination of climate policies. The slow progress of the climate policy negotiations under the United Nations Framework Convention on Climate Change has made it obvious that global cooperation is not achieved easily. This is matched by game theoretic prognosis of a "cooperation paradox". But game theory may also help to identify ways to overcome the dilemma: A better understanding of the motivations for unilateral climate policy as well as of ways to raise the level of cooperation might contribute to facilitating political negotiations. We briefly recapitulate the cooperation dilemma before discussing rationales for unilateral mitigation and options to improve global cooperation in turn.

4.1 The paradox of international environmental agreements

When nation states have the choice of contributing to a global effort to reduce GHG emissions, they face a strong collective action problem. This is because everybody can benefit from the abatement of one party without contributing to the associated cost of abatement, while the costs are borne by the abating state alone. There is no world government that might resolve this problem by devising and enforcing policies or contracts. Carbon leakage and the green paradox exacerbate the problem: reducing demand for fossil fuels in one region will lower their world market price, thus inducing increased consumption in other regions; further, announcing climate policies without deploying appropriate and globally coordinated instruments can shift the intertemporal fossil fuel extraction schedule towards the present, thus lowering prices, spurring demand, and increasing emissions (cf. Section 3.1). Hence, to game theorists, the game of climate change mitigation has the familiar incentive structure of public good provision.

Consequently, climate negotiations have been analyzed in terms of stylized games such as Prisoners' Dilemma or Chicken Game (Pittel and Rübbelke 2012). It is well known that cooperation is not an equilibrium of these games. However, one should be weary of the conclusions drawn from these simple games – other than the obvious point that such incentives hamper cooperation – due to their long list of strong assumptions. The standard prisoner's dilemma is a simultaneous, one-shot game with discrete choices. Among other things, the game abstracts from the fact that nations communicate, interact repeatedly in various matters, and can graduate their ambitions and sanctions.

One approach that has received broad attention in the game theory literature is the idea that introducing international environmental agreements (IEAs) may change the rules of the game and thereby give rise to a more cooperative outcome. Indeed, the seminal analyses show that agreements raise cooperation above the purely non-cooperative case (Hoel 1992, Carraro and Siniscalco 1993). Alas, the voluntary participation in such self-enforcing agreements remains low, especially when the gains from cooperation are large (Barrett 1994).

Game theoretic analysis relies on CBA with continuous benefit and damage functions, yet as we have discussed above, CBA may not be the appropriate tool when the danger of catastrophic impacts, even at low probabilities, is taken into account (cf. discussion of Weitzman 2009 in Section 2.3). One study that analyzes catastrophic impacts that occur at a certain climate threshold in the framework of coalition formation finds that the threat of disaster suffices to overcome the cooperation problem (Barrett 2011). Intuitively, nature becomes the credible enforcer that is missing in the international climate policy domain. But the same study also shows that uncertainty about the threshold overturns this result, as uncertainty transforms the discontinuous disaster into its (smooth) expectation.

Given the reluctance of several world regions to coordinate a global climate agreement, are there any options to improve cooperation? What are sensible strategic choices for first movers? Should they wait for action by others, or are there good reasons for ambitious countries or cities to develop good examples? There are two basic arguments in favor of such action by first movers. First, a number of rationales and mechanisms make unilateral initiatives economically rational even in presence of free riding incentives. These include: efficient policies, technological change, local co-benefits, international transfers, issue linking, and ethical considerations. Second, unilateral action can prepare the ground for more international cooperation in the future. The following two subsections discuss these in turn.

4.2 Rationales for unilateral action

While the standard game theory analysis is predicting a climate policy cooperation failure and real-world negotiations on a meaningful international climate policy agreement succeeding the Kyoto Protocol have been stalled since the 2009 UNFCCC conference at Copenhagen, a number of regions are already adopting climate policies varying in scope and level of ambition. The EU has adopted the most far-reaching package of climate policies and aims at reducing its GHG emissions by 20% in 2020 relative to the year 1990 (for an overview of recent EU climate policies, see Oberthür and Pallemaerts 2011). The EU also aims towards increasing the share of renewable energies to 20% of the primary energy mix in 2020. To achieve these goals, the EU emission trading system (EU ETS), a company-level cap-and-trade system covering roughly half of European GHG emissions was implemented in 2005 (Ellerman et al. 2011). Additional policies especially in the sectors not covered by the EU ETS include technology standards such as a fleet-level CO_2-intensity standard for cars and biofuel mandates (Creutzig et al. 2011), as well as national-level renewable energy targets and policies. Germany specifically aims at implementing a particularly ambitious climate policy with its "energy U-turn", which was initiated after the 2011 Fukushima incident. The goal is to simultaneously phase out nuclear energy and reduce GHG emissions by 40% in 2020, and by 80-95% in 2050, relative to 1990.

Beyond the EU, a number of policy initiatives for adopting GHG pricing by means of emissions trading are under way. New Zealand has introduced an ETS in 2010. Australia is implementing an ETS subject to fierce political contests (Jotzo 2012), and South Korea plans for the adoption of its ETS by 2015. On the sub-national level, California envisages implementation of its regional cap-and-trade system for 2013, with the intention to link to the ETS in Quebec planned to commence operations in 2013, and perhaps also to the Regional Greenhouse Gas Initiative (RGGI) trading system in the northeastern US operating since 2009. Perhaps most notably, in China five cities and two provinces are in the process of setting up pilot emission trading systems to inform a national cap-and-trade system envisaged to commence operations after 2015 (Petherick 2012, World Bank 2012).

In addition to carbon pricing policies, investments to renewables have expanded considerably in recent years, with 118 countries having adopted renewable energy targets in 2011. The most important support policies are feed-in tariffs and renewable quotas or portfolio standards, where a general trend of weakening these schemes was observable after 2009 due to the global economic crisis and austerity policies. Total global net investment into renewable power capacity was US$ 262bn in 2011, which was US$ 40bn higher than the same figure for fossil power generation. China (US$ 52bn) leads investment into renewables, closely followed by the United States (US$ 51bn) and Germany (US$ 31bn). Due to the relatively low load factors of renewable power, however, the share of modern renewable power generation (excluding hydro) increased only from 5.1% in 2010 to 6% in 2011 (McCrone et al. 2012).

Despite these unilateral actions, in their analysis of 76 countries' emission reduction pledges made under the Copenhagen Accord Rogelj et al. (2010) find that a conservative interpretation of these pledges implies virtually no difference to business-as-usual emissions in the year 2020. A more optimistic interpretation assuming a closure of potential loopholes from land-use and forestry accounting and overallocation of permits under the Kyoto Protocol (especially to Russia), as well as pledges implemented at the upper end of their proposed range, would yield about 5 Gt annual emission reductions compared to business-as-usual in 2020. Freezing global emissions at the conservative 2020 estimate until 2050 and beyond would lead to global warming of 3-4°C above pre-industrial levels by 2100 with 50-68% probability. It leaves a 5% likelihood of 5°C warming in 2100, with temperatures continuing to rise thereafter. This indicates a gap between the collective agreement to limit global warming to 2°C as endorsed in Copenhagen, and individual countries' actions (see also UNEP 2011).

Can this situation be analyzed in terms of the standard game theory analyses outlined above? An obvious interpretation may be that the gap between collective ambition and individual reluctance of countries confirms the diagnosis of a dilemma situation. Countries unilaterally reducing emissions via carbon pricing and renewables policies take on the role of "chickens", with the rest of the world having a free ride on their reduction efforts. However, a thorough assessment of empirical climate policies in terms of game theory is not available, and both common sense and the available scientific literature suggest that there are additional rationales informing international climate negotiations and unilateral emission reduction activities that require an extension of the simple standard model.

Co-Benefits

It is sometimes argued that local and regional co-benefits from emission abatement, such as cleaner air and reduced energy imports, increase unilateral benefits of abatement and can thus motivate unilateral emission reductions (Ostrom 2010, Pittel and Rübbelke 2008). The argument is that including co-benefits in the cost-benefit calculus of mitigation reduces the effective costs of mitigation, thus motivating higher levels of unilateral emission reductions compared to the case where they are not accounted for (Bollen et al. 2009). Going further, some argue that there are many advantageous negative costs or ‘win-win’ options for reducing or adjusting energy consumption, which don’t even require resorting to climate change mitigation benefits (e.g. Enkvist et al. 2007).

The critical question in this context is why welfare-improving policies in other issue areas such as local air pollution are not implemented in the first place. Conceptually, if all policy goals are addressed with first best instruments to balance marginal costs and benefits, it is not obvious that climate policy will induce any positive effects regarding additional policy goals. By definition, any reduction beyond those that are optimal will raise overall costs.

Clearly, where the introduction of climate policy enables improvement over previously *second best* implementation of policies (e.g. due to limited government capacity), climate policies may induce local or regional co-benefits. Thus, careful examination is required whether co-benefits can actually be attributed to climate policy. Also, it needs to be considered if studies on low- or negative-cost abatement potentials have considered the full costs of abatement options, including institutional and transaction costs or intangible amenity values of certain technologies.

Finally, there can be non-material co-benefits from unilateral climate policy. Some agents may have a preference for contributing to emission reductions that may be derived from their conviction of the ethical value of emission reductions. Such agents will derive benefits from contributing to the global public good of emission reductions or by sticking to unilaterally adopted permit budgets elicited through ethical reasoning, even in presence of the free rider dilemma. This may be motivated by the hope for reciprocal behavior of other agents in other world regions (Ostrom 2003), a ‘warm glow’ sensation (Andreoni 1990), or the non-material internal reward from individually and collectively acting in a manner considered to be morally sound (see also below).

Low-carbon technology development

The costs of low-carbon technologies such as renewables have decreased significantly in recent years, driven by increased technology adoption and R&D efforts (IPCC 2011). To the extent that firms or countries face sufficient demand e.g. as secured by a long-term price on carbon and an expectation to be able to capture the scarcity rent of such novel low-cost low-emission technologies through viable patent protection, they face a market-based incentive to develop these technologies (Edenhofer et al. 2006). Combined with the expectation of network externalities and economy of scale agglomeration dynamics in green technology industries, as well as the regional benefits believed to be associated with these technologies such as ‘green jobs’ in addition to enhanced competitiveness from technology leadership, this rationale has motivated first mover behavior at the national level expressed e.g. in ‘green industrial policies’ in Germany in recent years (BMU/UBA 2011). However, in presence of international spillover effects from technology learning (Jaffe et al. 2005), the magnitude of the technology development incentive for firms and the related national social benefits of green industrial policies remain unclear. In fact, despite its prominence in the public debate, little research is available to assess the validity of this rationale for unilateral action in low-carbon technology deployment and development.

For players who act as first movers e.g. because they have high preferences for emission reductions, there is another strategic rationale for unilateral investments to low-carbon technologies. Notably, if these investments reduce technology costs for other world regions they will ‘leverage’ additional mitigation as – *ceteris paribus* – other regions will increase the deployment of these less costly technologies. Faced with the decision to invest resources to domestic emission reductions or strategic technology development, first movers will thus allocate a larger share of their expenditure on investments that strategically reduce the costs of low-carbon technologies (Heal 1999).

Heal (1999) also points out that if the costs of low-carbon technologies can be reduced below the costs of competing emission-intensive technologies via learning effects, the climate stabilization game may in fact be a coordination game with two equilibria. The first is one where the world remains locked-in to an emission-intensive energy system, and the other, where collective investment into low-carbon technologies reduces their costs so much that they become universally adopted due to economic incentives and market forces. Clearly, the prospect for this promising avenue heavily depends on the cost reduction potentials for low-emission technologies compared to emission-intensive options. As noted above, the 164 scenarios analyzed by IPCC (2011) indicate that within the 21st century such a dramatic large-scale shift in the relative costs of technologies cannot be expected. This is due to the ample availability of fossil energy carriers and technologies at low-cost relative to carbon-free technologies.

Signalling

One explanation as to why international cooperation is seriously hampered might be the presence of ‘asymmetric information’ (Afionis 2011). For instance, it is well conceivable that negotiators are only imperfectly informed on their interlocutors’ perceived benefits from climate change mitigation, which are not exclusively determined by physical climate damages, but also by political considerations as well as ethical judgments (Gardiner 2004). With such informational asymmetries, actors may face uncertainty on whether they are actually confronted with a prisoners’ dilemma, in which non-cooperation constitutes a dominant strategy, or rather a game of coordination, in which there is no incentive for any player to unilaterally deviate from the cooperative outcome (Caparrós et al. 2004). A pessimistic expectation of the benefits obtained by other actors’ via climate change mitigation can then render cooperation impossible, even if it would be in both players’ best interests. Unilateral action by an actor with high benefits as well as high mitigation costs can then act as a signal that the actor’s benefits are indeed high enough to mandate concluding a long-term agreement that includes side payments to finance abatement in other countries (Jakob and Lessmann 2012).

An alternative, related incentive for unilateral action arises if all actors’ abatement costs – even their own – are only known with uncertainty but display a positive correlation. An actor who discovers that he has low abatement costs may in this case engage in unilateral action in order to signal to other actors that their costs are likely to be low as well, and hence provide them with an incentive to increase their mitigation levels (Brandt 2004).

4.3 Options to improve global cooperation

Besides the first mover rationales that may enhance global cooperation outlined above, there are at least five further options that provide starting points for alleviating the global cooperation problem.

Burden-sharing and financial transfers

International transfers are an important tool to foster cooperation as they enable sharing the gains from improved cooperation: Countries that are more willing to pay for mitigation can compensate other countries to reduce emissions if these have cheaper mitigation options at their disposal. A number of studies have investigated the prospect of transfers using numerical models of coalition formation to factor in heterogeneity among countries. Two approaches frequently pursued are (a) burden sharing through emission permit allocations and (b) transfer rules aimed at coalition stability.

Examples of the former are found in the burden sharing literature (e.g. den Elzen and Lucas 2005), but similar permit allocation schemes, ranging from equitable transfer schemes (e.g. following egalitarianism or historical responsibility) to pragmatic schemes such as "grandfathering" have been incorporated in the analysis of self-enforcing agreements (Altamirano-Cabrera and Finus 2006). However, insofar as these allocations are not derived so as to induce strategic effects, they show little or no effect on cooperation. By contrast, Lessman et al. (2010) demonstrate that strategic use of permit trading can facilitate the inclusion of non-signatories via flexible mechanisms like the Kyoto Protocol's Clean Development Mechanism.

Surplus sharing schemes that are designed to favorably alter incentives show a stronger impact on coalition formation (Nagashima et al 2009). In particular under "optimal surplus sharing", i.e. payoff transfers that stabilize coalitions (cf. Carraro et al. 2006; McGinty 2007, Weikard 2009), cooperation is much improved compared to the absence of transfers: 56 percent of the cooperation failure (difference in total welfare between non-cooperative Nash equilibrium and full cooperation case) is overcome. With a different model and the same idea of optimal transfers, only 5% of the initial cooperation failure remain (Carraro et al. 2006). Earlier studies in this strand of literature also find significant increases in participation due to strategic transfers (Botteon and Carraro 2001; Eyckmans and Tulkens 2003). Thus, as highlighted in Section 3.2, a strong conclusion that arises from these studies is that in order to be effective, strategic implications of transfers should to be taken into account in addition to normative considerations of burden sharing.

In contrast to the models investigating permit allocation-based transfers, models analyzing transfers in aggregate payoff do not specify how transfers are implemented and when they occur empirically: In dynamic models, which often span several centuries, neither the beginning nor the end of the time horizon are realistic points in time for a one-time side payment. New institutions of climate finance to implement these transfers are therefore required. Obvious candidates are funds such as the Green Climate Fund (UNFCCC 2010). The volume of transfers that stabilize coalitions may however be large, and it is not obvious whether countries are willing to agree to such explicit transfers.

Technology (clubs)

Development of low-carbon technologies can potentially reduce the cost of climate change mitigation and thus the costs of joining a climate agreement. But unless better technologies make abatement individually rational, the incentive to free-ride will remain. Still, technology research and development (R&D) offers at least two ways to enhance the incentive structure by either exploiting international knowledge spillovers associated with innovation, or by setting up a technology treaty rather than an environmental agreement. The former proposal links international emission reduction agreements to cooperative R&D efforts that are designed to restrict access to the fruits of these efforts – more efficient technologies – to the club of signatories. As joint R&D efforts generate a club-good surplus to be allocated between the cooperating parties, the net costs from mitigation are reduced and the adoption of more stringent abatement targets is facilitated (Botteon and Carraro 1998, Lessmann and Edenhofer 2011). However, institutional arrangements need to ensure that the benefits from joint R&D are indeed restricted to the signatories, which is challenging.

Other studies explore treaties that are tailored to produce "breakthrough technologies". In this setup, the prospect of cooperation only increases if there is a technology with increasing returns to adoption. In view of today's available technologies, however, there is no likely candidate exhibiting these features (Barrett 2006). Conclusions regarding the potential for cooperation are more optimistic when R&D is conceptualized as reducing the costs of technology adoption (Hoel and de Zeeuw 2010).

Trade policies

Without full cooperation in climate change mitigation, the existence of international trade will lead to carbon leakage. Moreover, abating countries are at a competitive disadvantage in international markets. One obvious option may therefore be to combine climate policy with trade policy such as carbon border tax adjustments which could reduce leakage and restore a level playing field (Stiglitz 2006a, b). Furthermore, trade sanctions or trade bans against non-signatories of a climate agreement can reduce the incentive to free ride to the extent where participation in the agreement increases (Barrett 1997, Lessmann et al. 2009).

Implementing linked trade and climate policies, however, is riddled with problems (Barrett 2010). The carbon footprint of traded goods, a prerequisite for meaningful border tax adjustments, is notoriously difficult to evaluate. The threat of punitive sanctions is often not credible, as the cost of limiting free trade cuts both ways. Moreover, it is quite possible that countries would retaliate; sanctions and counter-sanctions could escalate into trade wars. It is therefore important that carbon tariffs or trade sanctions are generally considered to be legitimate, which might reduce the risk of retaliation. Finally, it is not obvious whether trade sanctions would conform to the rules of the World Trade Organization (WTO), even though the case that they can conform be made (Perez 2005), and it has been argued that, given a broad sense that sanctions are legitimate, conforming with WTO rules is not crucial (Barrett 2010). Despite these complications, trade policies have the appeal of being the most obvious mechanisms to facilitate unilateral climate policy and to enforce an agreement; hence it seems likely that sanctions will be discussed in future climate policy negotiations (Barrett 2010).

Repeated interaction: Punishment, reputation, and norms

The one-shot perspective of the standard climate policy game neglects that interaction of nations is not restricted to a single time step and a single issue. Rather, nation states will negotiate contracts over a range of topics, and even an agreement on a single issue may have many commitment periods that require separate negotiations. Thus, one may argue that international climate agreements are more aptly described as repeated games, which have a distinctly richer strategy space. In particular, strategies can be contingent on the previous behavior of the opponent, and in turn must take into account the reactions of the opponent. Further, defectors may be punished, while cooperators may build a reputation, to name two prominent examples that we discuss in turn.

The threat of punishment can only then effectively deter free riding if it is credible, i.e. once defection has occurred it must be beneficial for the punisher to carry out the punishment. This makes punishment a tradeoff of being severe enough but not too expensive so as to become non-credible. For example, in Froyn and Hovi (2008) the threat becomes credible only when a fraction of the signatories carry out the punishment; the remaining signatories continue to "cooperate" and thus maintaining a high level of payoffs for all signatories. Asheim and Holtsmark (2009) generalize this idea for continuous strategies and they find that as long as the discount rate is sufficiently low, a broad and deep treaty can always be implemented. In Heitzig et al. (2011) punishment takes the form of a higher future emission reduction burden for the defector (proportionally to her shortfall), and a correspondingly lower burden for the punishing parties, which makes the threat credible. These results not only show that the well-known result that the prisoners' dilemma can be overcome in its (unlimitedly) repeated extension also translates to the climate game, but they also suggest first ideas for practicable implementations.

Incorporating the effects of reputation reverses the burden of proof compared to punishment in the following sense: rather than avoiding punishment, cooperative behavior will establish the player as worthy e.g. to receive voluntary donations from others. Laboratory experiments show that reputation effects in alternating games of public good provision and indirect reciprocity increase cooperative behavior (Milinski et al. 2002, 2006). Such desire to build a good reputation may over time turn into societal norms of good behavior. In how far nation states value norms or their reputation, and how it compares to economic incentives to free ride is difficult to quantify. The following paragraphs report studies that have made efforts to take genuine ethical considerations into account.

Ethics

Ethical considerations that impact the actual choices of people and nations can make a difference to the prospect for abatement, cooperation, and welfare. Previous literature on the provision of public goods has taken into account that contributing may be seen as a moral obligation (Sudgen 1984), or that at least "impure altruism" is at play, when players are not entirely selfless but receive a "warm glow" feeling from contributing (Andreoni 1990), or that contribution signals information regarding wealth or income of players engaged in status competition (Glazer and Konrad 1996). In the economic analysis of international environmental agreements it is obvious that if every player takes the benefits of its own abatement on others fully into account when determining their own behavior, the social optimum - i.e. full cooperation - will emerge. But even when concern for others plays only a small role the effects on cooperation may be large. Introducing even a little altruism may give rise to a much higher participation in climate policy (van der Pol et al. 2012). Similarly, a preference for "fair burden sharing" of mitigation may stabilize full co-operation (Lange and Vogt 2003).

The magnitude of people's willingness to take the fate of others into account in their decisions is an exogenous assumption in most economic analyses. It is usually assumed that this willingness is zero, i.e. agents base their decisions on pure self-interest. However, the concern for climate impacts on others is an endogenous issue in the public debate about intertemporal and interregional impacts of climate change and fairness. In these debates various questions arise. For example: How does a citizen in the European Union or the United States value the risk of submergence of low-lying islands such as the Maldives, possibly prior to the end of the 21st century? In the terminology of Keohane (1984), to what degree do people adopt a cosmopolitan welfare function in making their decisions? Do rich countries accept the claim that their historically high emissions oblige them to adopt more stringent abatement efforts? Is there a 'moral incentive' to refrain from free riding? Ultimately, the behavioral consequences from these normative considerations are empirical questions (notably, Lange et al. 2007, is a rare empirical inquiry into the normative principles of actors in international climate policy). An open societal discussion of ethical issues, where each individual and each community is free to make an informed decision on her ethical preferences, is the proper place to deal with these normative considerations in policy. It seems rational that societies where a majority of citizens are willing to take such considerations into account and aim to convince citizens in other regions to act similarly would signal their preference to these other regions by acting as good examples as to how a sensible climate policy portfolio may be deployed in their own backyards.

5. Think globally, act locally? The challenge of polycentric governance of global commons

The review of the standard game theory literature in the previous section indicated that there are certain incentives for regions to act as first movers in climate policy, and that transfers, sanctions and in particular repeated interactions and ethical considerations can make a substantial difference to whether cooperative climate policy is feasible. Elinor Ostrom and the literature on fiscal decentralization and fiscal federalism offer additional perspectives indicating that the cooperation problem in climate policy may not be insurmountable. Arguing that local mitigation action can facilitate international cooperation, Ostrom (2010) challenges the conventional wisdom that free riding, carbon leakage, and the green paradox preclude options for unilateral action. She suggests that a polycentric governance approach that recognizes the existence of multiple political actors at different levels provides a more promising and realistic analytical framework to analyze real word climate policy, as opposed to the standard view of centralized nation states as the key agents of policy making.

The perspective suggested by Ostrom has analytically been developed to some extent in the literature on *vertical* fiscal decentralization on the one hand and *horizontal* fiscal federalism on the other (for an overview in the environmental policy context see Dalmazzone 2006). In contrast to the literature on international environmental agreements, the literature on vertical fiscal decentralization does not assume a unitary government but acknowledges the dispersed allocation of power to adopt environmental policies at different levels of governments. It explores the potential of decentralizing policy in order to reduce mitigation costs. Such reductions of mitigation costs might both enable more ambitious unilateral emission reductions and reduce the incentives for free riding at the international level. The literature on horizontal fiscal federalism takes into account different degrees of mobility of capital and population, as well as a richer set of policy instruments. It derives ideal conditions under which efficient internalization of externalities is feasible even without an explicit global environmental agreement (Hoel and Shapiro 2003).

5.1 Vertical fiscal decentralization

The literature on *vertical fiscal decentralization* analyzes the optimal deployment and design of policy instruments at different levels of government. Conceptually, efficiency gains from fiscal decentralization can result from the exploitation of asymmetric local and regional preferences for mitigation levels. The underlying reasons for diverse preferences among the population may be social norms or self-interested cost-benefit calculations, including co-benefits of climate policy on local air quality (see Section 4.2). According to the so-called Oates theorem (Oates 1999), vertical fiscal decentralization is welfare enhancing if it enables diverse preferences for mitigation (compared to the federal and global level) to be taken into account in the policy instrument setup. For example, Williams (2012) argues that for a pollutant that causes both local and transboundary damages, a federal-level pollution tax might lead to a more efficient outcome than federal command-and-control policy or a federal system of tradable permits. The main reason for this asymmetry is that federal governments can re-distribute the tax revenues to the state governments according to their local preferences (Williams 2012). By contrast, if the federal government has less policy instruments at hand than externalities, policies are necessarily inefficient.

Indeed, the unilateral climate policy efforts by California, Germany and most recently in China and Mexico, as well as numerous activities of various cities indicate that preferences at the local level might indeed differ substantially from preferences at the national or international scale. A key aspect of the vertical fiscal decentralization perspective is that policy efficiency crucially hinges on the efficient division of responsibilities as well as policies and, correspondingly, on the transmission of incentives across different government levels (Dalmazzone 2006). Recent case studies on vertical climate federalism argue that current climate policy structures within the US and EU are inefficient in this respect (Shobe and Burtraw 2012). One interesting avenue for future research in this field is to investigate the potential for improving coordination e.g. between EU-level and national member state policies such as the EU ETS and national renewable subsidy schemes to reduce mitigation costs below current levels.

A second promise offered by applying the fiscal decentralization perspective to climate policy is the possibility of local experiments leading to examples of best practices, which can be scaled up after their success has been proven. Decentralization might induce more policy innovation because a higher degree of heterogeneity of local governments can lead to multiple parallel experimental policies (Strumpf 2002). Such learning-by-doing efforts to reduce cost uncertainty might also reduce aggregate mitigation costs substantially (Ostrom 2012), but further conceptual work remains to be done.

In general, until now there are basically no quantitative estimates exploring the potential for mitigation cost reductions from a proper design of vertical incentives structures and policies. This appears to be an interesting field for future research (Shobe and Burtraw 2012).

5.2 Horizontal fiscal federalism

Analyzing the circumstances under which independent jurisdictions can provide local or global public goods in absence of a central government, *horizontal fiscal federalism* offers a strand of research that is complementary to the literature on IEAs reviewed in Chapter 4. In contrast to the literature on IEAs, horizontal fiscal federalism assumes independent jurisdictions competing for mobile population and capital by means of policy instruments such as taxes, subsidies and environmental standards. Some of the models developed in this field suggest that efficient regulation of transboundary pollution is possible even without explicit cooperative agreements, assuming that population is perfectly mobile and jurisdictions take into account the migration response to their own policy choices (Hoel and Shapiro 2003). Other models providing a more detailed description of the design of policy instruments (Wellisch 1994, 1995, 2000) show that even a global environmental public good can be provided at a Pareto-optimal level if first, capital and population are mobile, and second if there is a fixed supply of land that is taxed or on which governments can impose a head tax to the residents. However, if migration of population entails costs, transfers between regions are required for Pareto-optimal provision.

To a certain extent these models can be regarded as extending the scope of the Henry George Theorem – well established in urban economics (Fujita and Thisse 2002) – claiming that local public goods can be provided at an optimal level even without a central authority. If households are mobile, their preferences for local public goods are capitalized in the land rent because competing jurisdictions supply local public goods in order to attract people. Increasing population increases land rents because of the fixed supply of land, which in turn decreases the attractiveness of the jurisdiction for mobile labor. In equilibrium, taxing the land rent is sufficient to finance the optimal amount of the local public good. In this setting ‘voting with the feet’ or ‘Tiebout sorting’ (Tiebout 1956) - allows for an optimal revelation of preferences.

The intuition behind transferring this strand of literature to the climate context is that citizens will move to jurisdictions that provide local and global public goods according to their preferences. Governments take these preferences and the migration response of citizens into account when devising their policies. As a result, the mobility of capital and households combined with taxation of land rents substitutes for Coasian bargaining or a utilitarian policy by a central world government. Availability of sufficient policy instruments, the absence of market power and the prefect mobility of production factors results in a Nash equilibrium which is Pareto-optimal. Admittedly, these conditions are unlikely to be met in reality. However, the fiscal federalism literature illustrates that the assumption of immobile production factors used in the IEA literature is not innocent.

A second branch of the fiscal federalism literature adopts the more realistic assumption that only capital is mobile whereas population is immobile. In this setting the familiar result reappears with competition between jurisdictions precluding the efficient provision even of local public goods due to a so-called ‘race to the bottom’ (Zodrow and Mieszkowski 1986, Wilson 1986). Without intergovernmental cooperation, the problem of local public good provision cannot be resolved. By contrast, Ogawa and Wildasin (2009) claim that in a setting with immobile households and mobile capital decentralized policymaking can indeed lead to efficient resource allocation and global public good provision. However, Eichner and Runkel (2012) challenge this result arguing that the Ogawa-Wildasin assumption of fixed capital supply (and thus aggregate global emissions) even in presence of climate policy-induced changes in the net rate of return to capital is not very plausible. Eichner and Runkel demonstrate that if the capital supply elasticity with regard to the net rate of return to capital is – more plausibly so – strictly positive (i.e. capital stock dynamics are affected by climate policy), decentralized capital taxation and the provision of the global public good are inefficiently low. This analysis re-confirms the basic negative insight of this strand of literature in its argumentation that mobile capital and immobile households lead to sub-optimal levels of public goods and capital taxes.

As an avenue for future research in this field, it seems interesting to combine the analysis of local climate policy choice with local public infrastructure investment decisions. Such infrastructure (local public good) investments, financed e.g. by a local carbon tax that simultaneously provides a global public good, will enhance local productivity, thus attracting foreign capital. This effect may counterbalance the negative impact of capital mobility on optimal local tax rates and the provision of local and global public goods at least to some extent.

5.3 Outlook for theories of polycentric governance

To conclude, the quest for an efficient substitute for perfect global and inter-temporal Coasian bargaining or a central world government is a difficult one. Still, the approaches developed by vertical fiscal decentralization and horizontal fiscal federalism may indicate interesting directions for further analysis for two reasons. First, in these settings national governments have more realistic taxation instruments at their disposal. As such, this enables analyzing potential linkages between climate policy and public finance considerations. Second, the broader scope of the policy instrument portfolio facilitates the understanding of second-best climate policies, e.g. harnessing co-benefits from climate policy. Accounting for second-best settings will not automatically resolve social dilemma situations. However, it might indicate rationales and options that reduce the magnitude of the challenge for international climate negotiations. At the end of the day, national and sub-national action can likely not fully substitute international cooperation. However, it seems worthwhile to explore options how international cooperation can be complemented and enhanced by polycentric governance of the planet’s atmosphere.

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