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Fiscal Implications of Climate Change

Benjamin Jones
Michael Keen
Jon Strand

Abstract

This paper provides a primer on the fiscal implications of climate change, in particular the policies for responding to it. Many of the complicated challenges that arise in limiting climate change (through greenhouse gas emissions mitigation), and in dealing with the effects that remain (through adaptation to climate change impacts), are of a fiscal nature. While mitigation has the potential to raise substantial public revenue (through charges on greenhouse gas emissions), adaptation largely leads to fiscal outlays. Policies may unduly favor public spending (on technological solutions to limit emissions, and on adaptation), over policies that lead to more public revenue being raised (emissions charges). The pervasive uncertainties that surround climate change make the design of proper policy responses even more complex. This applies especially to policies for mitigation of emissions, since agreement on and international enforcement of cooperative abatement policies are exceedingly difficult to achieve, and there is as yet no common view on how to compare nearer-term costs of mitigation to longer-term benefits.

FISCAL IMPLICATIONS OF CLIMATE CHANGE*

Benjamin Jones
Oxford University
benjamin.jones@economics.ox.ac.uk

Michael Keen
Fiscal Affairs Department
International Monetary Fund
Washington DC 20431, USA
mkeen@imf.org

and

Jon Strand
Development Research Group, Environment and Energy Team
The World Bank
Washington DC 20433, USA
Jstrand1@worldbank.org

I. INTRODUCTION

Climate change is, to a large degree, a fiscal issue. In itself, it is simply an externality problem, potentially calling for public intervention to limit ('mitigate,' in the jargon of the climate literature) harmful emissions. But it is an extraordinarily complex externality, both technically and politically, making appropriate measures correspondingly hard to design and (even more so) secure agreement on. Moreover, the economic impact of changing climates—now well-known[1]—will be felt, for good or bad, on both tax and spending sides of governments' accounts. And there are very specific challenges posed by the need for measures (of 'adaptation') to come to terms with—whether limiting damage or exploiting potential benefits—the climate change that will remain, with the balance between mitigation and adaptation in itself an important question of policy design. These potential fiscal implications, moreover, are—or at least should be—among the first consequences of climate change to be widely felt: the science means that mitigation will take decades to reduce future climate risks, while adaptation issues already arise in many countries.

This paper reviews the fiscal challenges posed by climate change and what is known about how to address them. The aim is to provide a (reasonably) quick and comprehensive overview of the main analytical issues and lessons learnt. More detailed reviews of particular topics may be found elsewhere: Aldy and others (2010) and the contributions in Parry (2012) for instance, survey mitigation instruments. There seems, however, to be no unified overview of the full range of fiscal issues.

To this end, Section II sets out the key features of the public economics of climate change. Section III then considers fiscal aspects of mitigation, and Section IV considers core aspects of current policies in this area. Section V turns to adaptation and the newer topic of 'climate finance.' The paper devotes more pages to mitigation than to adaptation, for two main reasons. First, the most severe incentive and coordination problems arise in relation to mitigation, since international spillover issues are much more marked: one country's emissions ultimately affect all others, but most measures of adaptation do not. Second, while mitigation clearly requires public action, adaptation will and should be largely a matter of response by the private sector. Moreover, adaptation has simply attracted less attention. Section VI concludes.

II. CLIMATE CHANGE AS A PUBLIC FINANCE ISSUE

Climate change will have indirect effects on the public finances that may amplify the wider challenges it poses. Countries heavily dependent on tourism or on selling fishing rights, for example, or experiencing reduced agricultural productivity, may face significant reductions in tax revenues. More fundamentally, however, taxes and spending instruments have a purposive role to play in mitigating and adapting to climate change, and it is these that are the

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[1] The Appendix provides a refresher.

focus of the paper. This section starts by setting out key structural features of climate change viewed from a public finance perspective.

Climate change is an externality problem…

Emitters of greenhouse gases (GHGs) fail to recognize the aggregate damage they cause, so emit more than is collectively desirable. Attaining a long-run atmospheric CO_2 target of 550 parts per million, by many scientists considered necessary, requires slowing and then (starting in 2020–40) cutting global emissions (by 60–80 percent). But each country would prefer others to shoulder the costs of doing so—a classic "free-rider" problem. Indeed a unilateral reduction in emissions by one country reduces the marginal benefit of abatement to others, and so is likely to be to some degree offset by increased emissions elsewhere.[2]

…but a particularly complex one

The collective action problem is made more challenging by **_asymmetries_** in physical impact and past emissions. Emissions have the same effects wherever they arise, but those effects differ greatly across countries: they are most adverse in lower-income countries (and perhaps even beneficial in some wealthier ones), and often for the most vulnerable groups within them. Responsibility for current concentration levels also varies greatly: high-income economies generated about 80 percent of past fossil fuel-based emissions, and in that sense account for much of the prospective damage. But limiting that damage requires that others also cut emissions: China now emits more than the U.S., for example, and within a decade, most emissions will come from outside the OECD. Asymmetric interests and views on historical responsibility, with a clear tendency for those standing to lose most having lower past emissions, severely complicate identifying generally acceptable policy responses, and make it likely that some form of side payments between countries will be needed.

Dealing with climate change is also made difficult by its **_slow-moving, stock nature_**. Global temperature depends not on the current flow of emissions but on the cumulative stock, with emissions taking decades to have their full effect and then a century or so to decay. Thus little can be done to avoid temperature rise in the next three decades or so, and current economic difficulties make little difference to the case for future mitigation: these caused global emissions to fall temporarily in2009,[3] but the impact on the accumulated stock—given its sheer scale relative to emissions, and very slow rate of decay—is limited: even a 10 percent fall in global emissions lasting two years, for example, might reduce the stock of greenhouse gases by only around 0.1 percent—and by only around 2 percent in 2040 were the economic impacts to be permanent.[4] A still more profound implication is the strong inter-

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[2] Auerswald, Konrad, and Thum (2011) show that where a unilateral cut in emissions reduces the uncertainty associated with emission-related damages, the net impact may actually be an increase in global emissions.

[3] The International Energy Agency (IEA, 2009) estimated that global emissions fell by around 3 percent in 2009; but increased again in2010 to slightly surpass the 2008 level.

[4] Jones and Keen (2010).

temporal mismatch between the (early, and certain) costs and (late, and highly uncertain) benefits of reducing emissions.

Addressing the issues of ***inter-generational equity*** implied by this awkward inter-temporal structure requires assessing the impact now and into the future of mitigation efforts and remaining climate effects and then determining how to weigh them in designing policy. The latter has sparked particular controversy as to the appropriate choice of discount rate. One approach is simply to use a market rate as a summary statistic of implicit social judgments or through sheer pragmatism. Another has been to dissect the standard formula for discounting marginal increases in future consumption in the Ramsey model of an infinitely lived individual in a perfectly certain world at a rate of $\rho + \eta(C)G$, where ρ is the rate of pure time preference (comparing future to present welfare), η is (the negative of) the marginal utility of consumption and G the rate of consumption growth. The Stern Review (2007), notably, famously followed Frank Ramsey in deeming the discounting of future utility ethically indefensible, and took ρ to be 0.1 percent (non-zero only to the extent of possible global catastrophe). But this is not the only philosophically respectable position: others might argue, for example for a maximin approach; which, since the present generation is likely to be the poorer than its successors, climate damage notwithstanding, leads to quite different conclusions. The remaining elements of the formula are also open to debate: Dasgupta (2007) for instance, argues for a higher value of η than taken by Stern (two rather than one).

This controversy is now quite well-trodden. But it is not resolved. One response to this lack of consensus is to treat the discount rate itself as uncertain; which, since discount factors are convex in the discount rate, implies discounting at a rate below the expected discount rate (with that rate also falling over time). The conclusion, more generally, is simply that it remains the case that the position one takes on the proper discount rate can make a large difference not only to assessed damages from climate change but—as discussed below—to views on the proper level and rate of increase of carbon prices.

Arguably even deeper challenges arise from the ***pervasive uncertainty*** in the science of climate change. First, the trajectory of future man-made GHG emissions, over a natural planning horizon (say, the current century) is uncertain. Second, there is uncertainty on the long-term impacts of emissions on GHG concentrations, due to variable and uncertain absorption rates for carbon in soil and oceans. Third, the climate implications of given GHG concentration level changes are highly uncertain. This is true of both gradual effects (for instance on cloud formation, whose overall effect on warming is uncertain), and the possibility of catastrophic events, whose probabilities—while likely low—are themselves unknown. Finally, the impacts of any given climate change, on human societies and overall human welfare, given our adaptive responses to such change, is highly uncertain. The implications of this uncertainty for policy design are profound.

One issue posed by uncertainty is its implications for the proper discounting of future effects. A straightforward approach is to discount expected future consumption at a rate that adds a risk premium to the standard formula above. Weitzman (2009) argues however, that more

profound consequences follow on recognizing that the relevant uncertainty in relation to extreme events is necessarily Knightian, since past observations can provide little if any guidance on the distribution of outcomes. Taking the expectation over distributions of possible outcomes can plausibly lead to a distribution with 'fat tails;' and with the probability of these low outcome events declining less rapidly than the associated marginal utility of consumption increases, the expected marginal utility from an additional unit of consumption in all future states of nature becomes infinitely (or at least) very large. The consequence of this 'dismal theorem' is that a concern to guard against catastrophe will dominate policy choices, whatever view is taken on the more traditional discount rate issue (and many others) above. The practical importance of this observation, and the conclusions to be drawn from it, have attracted much debate: Kousky and Cook (2009), for example, provide statistical evidence that the distribution of losses for wind and flood events in the US may be "fat tailed".[5] Others, however (including Nordhaus (2011), and Pindyck (2011)), take the view that such possibilities do not cause fundamental problems for economic analysis.[6] And Aldy et al (2010) point out, for instance, that since many catastrophic events will have significant transition periods and may come with some warning, the development of 'last resort' technologies is likely a wiser response than is cutting emissions to levels providing reasonable assurance against such catastrophes. Nonetheless, the debate makes clear that tail events are, in an important sense, different, and may need tailored responses to address them.

The possible ***irreversibility*** of many climate effects causes particular problems when coupled with uncertainty. On one hand, the possibility of irreversible environmental damage—increased atmospheric concentrations, extinction of species, and catastrophic events—points to a "precautionary principle:" act now to avoid the possibility of bad future outcomes. But the prospect of better information on the likely extent and nature of damage, and of improved technologies, argues for the opposite: delay action to avoid incurring costs (including through mitigation) that may prove unnecessary.[7] Balancing these two considerations is complex, and— beyond some consensus that the risk of catastrophe argues for caution—assessments of the practical implications differ.[8] The consensus in the literature, exposed e.g. in Fisher and Narain (2003), however seems to be that the delaying ("wait-and-see") factor dominates the irreversible damage factor: additional waiting is then typically optimal (an unpalatable result for many environmentalists). Problems caused by irreversibility are increased by the

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[5] They also identify weaknesses in traditional assumptions regarding the independence of different weather related risks, significantly amplifying concerns regarding potential losses from extreme weather events.

[6] The basic argument is that damages are always bounded so that the fundamental problem in Weitzman (2009), that expected climate damages can be infinitely large, does not apply. A modified argument appears in Weitzman (2011). See also Strand (2009). Kousky et al (2009) discuss practical, anticipatory, measures to meet the possibility of "mega-catastrophes".

[7] See for example Pindyck (2000).

[8] Kolstad (1996); Fisher and Narain (2003); O'Neill and others (2006); Pindyck (2007).

existence of long-lived infrastructure investments that may imply high levels of GHG emissions long into the future, but are costly to change in the short and medium terms.[9]

Climate change and responses to it are likely to *interact with other market failures*. Innovation in mitigation and adaptation, for example, may convey externalities and so raise questions of policy support. Not least, the design of mitigation instruments may be affected by their impact on revenue and the wider fiscal system. And addressing deforestation (about 15 percent of GHG emissions) may be hindered by weak property rights and governance.

Further complications arising from the *exhaustibility* of the fossil fuels from which most emissions arise. Suppliers must decide not simply whether, but also when, to extract oil, gas, or coal, or to cut trees—which can have powerful implications for the impact of mitigation measures. And those decisions may themselves be distorted by another set of market failures.

All this adds up to an extraordinarily complex setting in which to design policy.

III. FISCAL INSTRUMENTS FOR MITIGATION

Fiscal instruments are not the only way to reduce GHG emissions, but can be particularly well-targeted. Performance standards for cars, for example, limit fuel used per mile traveled but do not charge drivers for the emissions from the marginal mile traveled. And there are a wide range of fiscal instruments that could be used: a tradable performance standard, for example, would require firms to purchase permits to the extent that the average emissions intensity of their output exceeds some threshold. But the best-targeted policy is to charge an appropriate price for GHG emissions, since this efficiently exploits all opportunities for emission reduction. A tradable performance standard, for instance, provides the same incentive to reduce emissions per unit of output as would a carbon prices; but, in effectively rebating the part of that charge corresponding to baseline emissions combines this with an output subsidy that counteracts the impact on emissions.[10] Accordingly, this section reviews issues in the design and assessment of appropriate carbon prices.

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[9] See Shalizi and Lecocq (2009), Strand, Miller and Siddiqui (2011).

[10] To see this: A firm's profits under such a scheme are $\Pi = R(X) - C(e, X) - p(e - \bar{e})X$, where R denotes revenue, output is X, emissions per unit output are e, the emissions standard is $\bar{e}$ and the permit price is p. Rewriting, $\Pi = \Pi_c + sX$ where $\Pi_c = R(X) - C(e, X) - peX$ would be profits under a carbon price of p and $s = p\bar{e}$ acts as an output subsidy.

A.   Principles of Carbon Pricing[11]

Pigovian pricing

The classic prescription for externality problems—facing polluters with a price for their emissions equal to the marginal social damage they cause—implies charging a price for emitting CO_2 equal to the present value of the marginal social damage it causes. Denoting the stock of emissions at time t by $S(t)$ and the associated marginal damage by $D'(S(t))$, [12]this implies a Pigovian charge at time u of

$$P(u) = \int_u^\infty D'(S(t))e^{-(\delta+r)(t-u)}dt \qquad (1),$$

where δ denotes the rate at which the stock decays and r the discount rate. The stock nature of the externality means that the corrective price for current emissions generally depends on future emissions; and a lower discount rate implies a higher carbon price, as does slower decay.

Faced with such a 'carbon price'—an addition to the price paid for the underlying resource itself (such as coal)—emissions will not be taken beyond the point at which the marginal cost of reducing ('abating' or 'mitigating') those emissions is less than that price. In this way, the marginal social cost of abatement is equated to its marginal social benefit (from reduced damage). Efficiency requires—absent other market failures and/or equity concerns (returned to later)—that this carbon price be the same for all emissions, however and wherever they arise. The social damage from CO_2 emissions being the same wherever in the world they arise, efficiency requires that marginal abatement costs also be uniform, across countries and emitters. This requires identical carbon prices: otherwise the same emissions reduction could be achieved more cheaply by raising the carbon price on fuels, in regions or on activities in which it is low, and reducing it where it is high.

Arguably no less important than the level of the carbon price at any time is its evolution over time. One reason for this is that energy investments are commonly made for the long term— possibly decades—and with substantial sunk costs, so that efficient decision-making requires confidence on the future course of carbon prices. So too do incentives to innovate. From (1), the Pigovian carbon price evolves as $\dot{P}(u) = (r + \delta)P(u) - D'(S(u))$. All else equal, while a lower discount rate means a higher current carbon price it thus also means one that rises

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[11] Similar principles apply to other GHGs, but the discussion here follows much of the debate in focusing on mitigating CO_2 emissions—the largest (and most rapidly increasing) share of GHG emissions. Burning fossil fuels also generates other pollutants (such as nitrous oxides and particulates) that can cause significant local and regional harm. While carbon pricing can have significant co-benefits in reducing such emissions, they are best dealt with by differential charges related to each pollutant.

[12] The shape of the marginal damage function Is not entirely clear cut: damage is convex in temperature increase, but temperature increase is (somewhat counter-intuitively) concave in (linear in the log of) the concentration level.

less rapidly (because the present value of future damages then increases less rapidly as they draw nearer). And, ignoring decay, the efficient carbon price increases over time so long as most damage arises in the future, in the sense that the present value of future marginal damages is greater than it would be if today's damage persisted forever. This seems likely to be the case for several decades.

While the characterization in (1) is of wide applicability, the implied time path of the carbon price plays a particularly critical role in the context of exhaustibility. As in Hotelling (1931), the extraction decisions of competitive producers are then guided not by the carbon price at any moment but by the rate at which it increases in present value: extraction today will be more attractive than extraction tomorrow, all else equal, if that present value increases over time.[13] If, for instance, the carbon price simply rises at the rate of interest, then—unless the rate is so high as to choke consumption, and ignoring the possibility of backstop technologies—then there is no impact on extraction paths (or, hence, the course of global warming): the price to the producer simply falls by the amount of the carbon price. The intuition is straightforward: the long-run supply of the resource being inelastic, producers bear the full burden. Similarly, a carbon price growing at a rate higher than the rate of interest—or other policies pointing towards tighter limits in the future than at present--will tend to bring forward fossil fuel extraction and so accelerate climate damage: this is the "green paradox" of Sinn (2008).[14] How important this possibility is in practice has proved another focus of debate. Ploeg and Withagen (2009), for instance, show that the green paradox is less likely to occur when backstops that can replace fossil fuels are relatively inexpensive. Even when immediate extraction does increase, however, cumulative extraction may fall: this will be the case, Hoel (2010) shows, when extraction costs rise as the stock is depleted; and a similar effect may arise as the expectation of tighter future policies discourages exploration for new reserves. Perhaps most fundamentally, however, whether fossil fuels are best modeled as exhaustible is questionable: empirically, the evolution of resource prices is not well-described by simple Hotelling-type models; and stocks— especially of coal—are so large that the relevance of exhaustion is moot.[15]

Market imperfections

Using the proceeds from carbon pricing

Government receipts from carbon pricing—whether as tax revenue or from auctioning emission rights—can ease pressures on the public finances, which will likely remain

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[13] The carbon price is effectively a royalty on resource extraction.,

[14] Early treatments of the issue are in Sinclair (1994) and Ulph and Ulph (1994).

[15] The World Coal Organization reports that proven coal reserves are adequate for around 118 years at current usage, while proven oil and gas reserves are enough for around 46 and 59 years (http://www.worldcoal.org/coal/where-is-coal-found/).

extraordinarily severe in many advanced (and high emitting) countries for some time. They can enable cuts in other distorting taxes, or an increase in public spending, or debt reduction. And the sums at stake are potentially sizable. Recent legislative proposals for an emissions trading scheme in the US, for example, had revenue potential of around $850 billion over 2010–19 (the value of the third phase of the EU ETS 2013-20 is expected to be of similar magnitude): roughly 25 percent of the then-forecast cumulative US fiscal deficit, more than a quarter of total corporate income tax revenues, and around 0.5 percent of cumulative GDP.[16]

It might be tempting to suppose that carbon pricing can thus yield a "double dividend"[17] in the sense of not only mitigating climate change but also improving the overall efficiency of the tax system—in which case it might be optimal to set the carbon price *above* the Pigovian level. But in addition to this beneficial "revenue recycling" effect is a "tax interaction" effect: carbon pricing will affect, and possibly exacerbate, the distortions caused by the pre-existing tax system. By raising the consumer price of energy-intensive goods, for instance, it would have effects similar to a reduction in the after-tax wage, and thus reinforce the distortionary impact of labor taxes—implying an optimal carbon price *below* the Pigovian level,[18] by perhaps 15–20 percent. In some circumstance, however, the tax interaction effect could act in the opposite direction: in some developing countries, for instance, a tax on fuel inputs may increase efficiency by levying tax more effectively on final operators.

If the initial tax system is well-designed (climate concerns aside) then the two effects must cancel out: tautologically, it is impossible to raise the same revenue in a way that is better. In practice, however, initial tax systems may be less than perfect, and the political impetus behind carbon pricing may enable beneficial reforms that were previously unpalatable.

The best use of additional revenue from carbon pricing, including to offset any adverse equity impact (discussed below), will vary with countries' circumstances. In many developing countries, revenue from better carbon pricing would naturally be used to strengthen revenue mobilization. Several developed countries have previously used additional revenue from increased energy taxes to reduce social contributions, such "green tax swaps" being intended to reduce unemployment: Germany, for example, shifted around 3 percent of total tax revenue in this way in 1996–99. The likely effectiveness of such measures depends on the extent to which the burden of carbon prices can be shifted to factors other than labor. The (scant) empirical evidence does not suggest strong employment gains.[19] In any case, it is likely that many advanced countries will increasingly need to utilize receipts from emissions charging for fiscal consolidation.

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[16] Congressional Budget Office (2009a,b); Commission of the European Communities (2008a).

[17] Usage of this term differs: see Goulder (1995). For further references, see Goulder (2002).

[18] Bovenberg and de Mooij (1994).

[19] See, for instance, Carraro, Galeotti, and Gallo (1996).

Innovation

Proper carbon pricing is a critical anchor for efficient innovation. Technical progress—for instance, in developing carbon sequestration technologies—will be pivotal in dealing with climate change. Such innovation needs to be guided by carbon prices (present and prospective, over the long term) that reflect the social gains from developing less carbon-intensive technologies.

One strand of literature examines how the path of optimal carbon prices is affected if (as is likely) technological progress is endogenous to emissions charging and subject to forms of market failure other than the underpricing of emissions reductions—under the assumption that no other instruments are deployed. The exact prescription varies for different forms of knowledge spillovers.[20] Positive learning effects might imply a relatively higher carbon price initially, but subject to a lower than otherwise growth rate—falling back to the level in (1) (or even lower level) at some future date. However, an initial price below the Pigovian level may be appropriate where the set of useful ideas is viewed as limited, and their research and development has a "crowding out" feature, becoming progressively more costly.[21] Some studies argue that returns to innovation in green technologies could be mutually reinforcing (due, for example, to positive scale effects with respect to market diffusion), which might modify the path of optimal carbon taxation as the economy is shifted to a growth path where 'green' technologies dominate more (Acemoglu and others, 2011). However, constraints on substitutability of clean and dirty forms of capital, as well as the extent of the competitive advantages currently enjoyed by conventional technologies, mean that a steadily increasing carbon price over a sustained period is likely needed in practice.

More fundamentally, however, where innovation is subject to its own market failures an efficient response will require instruments beyond carbon pricing. Such failures potentially arise from standard problems of knowledge spillover in relation to R&D and learning by doing, potentially amplified in the present context by a time inconsistency problem: once innovations have proved their worth, governments may have an incentive to renege on the high carbon prices promised in order to induce that innovation.

Fiscal instruments have a potential role in overcoming market failures in climate-related R&D. Technical progress in dealing with climate change will be subject to the same broad market failures and challenges that affect all innovation: the inability of innovators to appropriate the full social benefits of their investments, and overcoming obstacles to rapid,

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[20] See Jaffe, Newell, and Stavins (2002) for a review of the empirical literature.

[21] See, in particular, Greaker and Pade (2008), who show that when the technology projects are mutually reinforcing, the carbon tax should typically start higher, while when projects have the "crowding out" feature, it should usually start lower, relative to the Pigou level.

wide diffusion of new technologies, in particular in low-income countries where they may have their widest application. Even aside from climate issues, many countries already offer generous R&D incentives (this being one feature of the intensified international tax competition in recent years). There is evidence that these do increase spending on R&D and patenting,[22] but they can be difficult to shape so as to target innovation conveying social rather than private benefit. And tax reductions may do little for innovative start-ups, since these are unlikely to generate substantial taxable income. Nonetheless, general R&D support measures should apply to climate-related innovation as to any other. There may though be a case for further fiscal measures reflecting, for instance, the costliness of catastrophic outcomes (putting some premium on geo-engineering solutions) and such sector-specific issues as the inability of private insurers to cope with particular risks from nuclear power. Although not without risk of waste, public spending to support private innovation can potentially be better targeted where social returns are likely most to exceed private.

It remains unclear whether fiscal support measures to encourage renewable energy developments so far—including, for example, capital grants and low interest loans for production capacity and new technologies development, feed-in tariffs, and tax credits—have proven cost-effective. The OECD (2008) estimated that support for biofuels in the United States, Canada, and the European Union, for example, amounted to around $11 billion in 2006, but returned emissions at a cost of between $960 to $1,700 per tCO2—around 70 to 130 times the current EU ETS price. This will be too pessimistic a view once learning-by-doing is taken into account, but stresses the importance of monitoring such spending—including through tax expenditure analysis—to inform policy formation in an increasingly important area.

What does seem clear, however, is that while it may be politically tempting to set a low carbon price and instead provide strong public support for innovation, this risks wasting resources by substituting, at the margin, relatively expensive R&D for relatively inexpensive mitigation. Fischer and Newell (2007), for instance, find that while there are likely to be considerable gains from an efficient combination of carbon pricing, R&D support and renewable subsidization, it is the carbon pricing component that is most critical.

Distortions in fossil fuel extraction

Some argue that fossil fuels are extracted too rapidly, which may call for a carbon price increasing at less than the market interest rate. This over-extraction may be because resource-owners may use 'too high' an interest rate (so preferring to extract the resource now and invest the proceeds, rather than leave it in the ground), either because their rate of discounting of future costs and benefits is higher than that chosen by a global social planner (due perhaps, to imperfections in credit and capital markets); or because they feel insecure in

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[22] Hall and van Reenen (2000), Jaumotte and Pain (2005).

their property rights (Sinn, 2008). This could be countered directly by taxing the sectoral return to capital or alternatively by having the carbon price rise at less than the interest rate. But the direction of effect is not entirely clear-cut. Insecurity of property rights might also lead to too little extraction, by discouraging any accompanying sunk investments it requires (including potentially in exploration): there is evidence that such insecurity reduces oil production, but increases deforestation (Bohn and Deacon, 2000). [23]

The limits of carbon pricing

There may come a point—indeed this is increasingly likely as mitigation efforts are delayed—at which it becomes clear that feasible mitigation strategies are unlikely to avert abrupt or catastrophic climatic shifts: these events may well be preceded by clues that a trigger point is approaching (Weitzman 2011) and generally involve transitions of decades or more, Fast-acting 'last resort technologies'—direct carbon capture from the air or geoengineering to deflect solar radiation—are then the only way to avoid these large effects (or at least buy time).

Much is already known about the science of these options. Experience from volcanic eruptions shows that deflection can work, and the physics and engineering of geoengineering are well understood. Moreover, operationalizing this could be cheap: Carlin (2006) puts the cost at only a few cents per tonne of CO_2. Barrett (2007) argues that at such low cost the free-rider problem becomes very much less marked. The concerns are in this case rather different. Beyond political incorrectness is a natural concern with unintended side effects.[24] Still more fundamental, perhaps, are the governance issues stressed by Barrett (2006): Who gets to control the global climate? It seems increasingly prudent, nonetheless, to take these options seriously.

B. Instrument Choice—Taxes, Cap-and-Trade, Hybrids[25]

Carbon pricing can be implemented through carbon taxation, cap-and-trade, or hybrids of the two. A carbon tax is simply one levied at the same specific rate on all emissions, whatever their source. Since carbon emissions are proportional to fossil fuel use (for a given fossil-fuel type, and in the absence of carbon capture and storage technologies), this could be charged not directly on emissions but on the use of fossil fuels—oil, gas, and coal—themselves. Under cap-and-trade, some fixed total of emission rights is issued, and firms trade to hold the

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[23] Strand (2009) shows that either the "insecure property rights" effect, or the "sunk cost" effect, may dominate, depending on parameter values.

[24] Carlin (2006) points out, however, that geoengineering has some advantages over mitigation: it preserves, for instance, the beneficial effects of higher CO_2 concentrations on some plant growth.

[25] Issues of instrument choice are also reviewed in Goulder and Parry (2008) and the contributions in Parry (2012).

permits they need. The price paid for the permit is then, in effect, a carbon price. 'Hybrids' let the carbon price vary (like cap-and-trade) but also allow some flexibility in aggregate emissions (like a tax): this might involve, for instance, cap-and-trade with a maximum price (at which unlimited permits would be issued). More generally, since no tax or emissions limit would remain unchanged forever, any scheme will in practice be some form of hybrid. Variants include a cap-and-trade scheme in which countries are allocated emission rights corresponding to business-as-usual and a central authority, financed by direct country contributions, controls emissions by purchasing and retiring them (Bradford, 2002). Investigating the relative merits of these instruments is a central challenge for the public finance of climate change and has received considerable attention.

Tax and cap-and-trade schemes can be[26] equivalent—in terms of aggregate emissions and government revenue—if emission rights are auctioned, the structure of abatement costs is known; and there is perfect competition in the markets for fossil fuels. Any outcome under some carbon tax can then also be achieved by cap-and-trade: auctioning permits in an amount equal to the level of emissions under the carbon tax will result in an equilibrium permit price equal to that initial carbon tax; so each firm will emit the same amount and the government will collect the same revenue. In practice, of course, these conditions rarely hold, and instrument choice becomes a real issue.

Box 1 elaborates on the comparison between these instruments. For reasons set out there, carbon taxation is then likely to be preferable to cap-and-trade. Recent experiences relating to the global economic crisis, for example—which caused prices in the EU emissions trading market to plummet during the second half of 2008—provides a powerful reminder that policy must be set with imperfect knowledge of future mitigation costs (and serves to illustrate the problem that setting a cap can lead to high price volatility in the carbon markets, potentially harming long-term investment decisions). Hybrid instruments (combining features of both taxes and caps) can improve on both, [27] though no instrument assures credibility—critical for guiding efficient investments in long-lived capital of the type common in energy markets. Carbon taxes provide certainty on carbon prices; cap-and-trade provides certainty on aggregate emissions.

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[26] "Can be" rather than "are" because equivalence also requires, for instance, effective competition in both product and permit markets.

[27] This general point is made by Roberts and Spence (1976).

Box 1. Aspects of instrument choice

Uncertainty tends to favor the use of tax- rather quantity-based instruments:

- *Errors in assessing marginal abatement costs* will arise under either tax or cap-and-trade schemes, but with different consequences (Weitzman, 1974).[28] If marginal abatement costs prove higher than expected, for example, cap-and-trade will lead to too much abatement (because it takes no account of that increased cost) whereas a carbon tax will lead to too little (because it does not allow for the increased marginal benefit of abatement when abatement is cut). In the climate context, such errors under cap-and-trade over any relatively short period are likely to be more costly than those under taxation: this is because marginal abatement costs rise rapidly as abatement increases, but emissions over any short interval make little difference to the accumulated stock, and hence to marginal benefit from abatement. The consequent gain from the use of tax schemes may be sizable (Newell and Pizer, 2003; see also Pizer, 2002 who argues for a combination of price and quantity instruments).

- *Volatility* of the carbon price may be greater under cap-and-trade, and *international spillovers* stronger, since aggregate emissions cannot respond flexibly to aggregate demand shocks. This may discourage mitigation-related investments by increasing the option value of waiting. In an international setting, the same effect can cause adverse macroeconomic spillovers as increased growth in one country has an amplified effect on the carbon price also faced by others (McKibbin and Wilcoxen, 2004).

Hybrids can in principle improve on either a simple tax or cap-and-trade. In practice, the choice is not between an unchanging tax scheme and a fully predetermined path for aggregate emissions: each would be updated in the light of emerging information, producing an outcome with elements of both. More generally, faced with uncertainty in abatement costs, the best policy in principle is neither a simple tax nor cap-and-trade, but a scheme allowing both the carbon price and total emissions to vary.[29] Such hybrids can take many forms, such as supplementing cap-and-trade with price caps and provision for 'banking' (saving) and 'borrowing' permits.

Credibility of future carbon prices is not easy to achieve under any instrument. One hybrid proposal, for instance, involves issuing very long term permits, to create a vested interest in the maintenance of tight emissions limits (McKibbin and Wilcoxen, 2002). Whether governments faced with an urgent need to limit emissions would be willing to pay market prices to retire long-term permits, however, is questionable. And carbon taxation may, through the revenue it raises, create a strong vested interest in the government itself. Some degree of international cooperation seems likely to be needed, in any event, to support the credibility of domestic policies.

Domestically, practical considerations tend to favor tax-based schemes. Implementing carbon taxes and cap-and-trade both require monitoring payments and emissions. And since what matters is the amount of fossil fuels ultimately burnt, not who does the burning, both can be implemented at any stage between 'upstream' (extraction, refining or import) and 'downstream' (the final burning). The general principle of restricting monitoring to as few points as possible suggests in each case an upstream focus—but with the difference that under cap-and-trade this may compromise the competitiveness of any auctioning process. Tax arrangements also fit well with the established expertise of tax administrations in relation to fuel and other excises, whereas cap-and-trade requires, in many countries, a new institutional apparatus. For the same reason, compliance for firms may be less burdensome if existing tax schemes are strengthened rather than new trading mechanisms

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[28] A standard diagrammatic exposition of the Weitzman argument is in Jones and others (2007).

[29] Dasgupta (1982), Roberts and Spence (1976). See Pizer (2002) for an evaluation of gains from such hybrid schemes.

created.

The equivalence between taxes and cap-and-trade may also fail under imperfect competition in fossil fuel markets. One reason is that fossil fuel demand is likely to be more elastic under a carbon tax than under a given cap, simply because the cap defines a more rigid demand. A fuel exporter that behaves monopolistically (as OPEC or some of its members may do) is likely to react with a higher export price in the face of a cap than when facing a tax: in effect, the cap serves as a coordinating device for imposing an export tax.[30] In consequence, the outcome for fuel importers will be less favorable under a cap policy.

The administrative implications of the two approaches also differ markedly. Implementing cap-and-trade, for example, requires new functions including determining baselines, allocating emissions rights, and verifying and enforcing compliance; it also raises a novel set of tax issues, many with complex international aspects. These include, for instance, whether to treat income derived from transactions in allowances as business income or capital gains. Particular issues arise when allowances are allocated free of charge: if the value is not taxed when received but only when the permits are sold, for instance, recipient firms may have an incentive to defer this tax liability by banking permits, if possible, rather than selling them now[31]—so distorting the market for permits.[32] Implementing an emissions tax, by contrast, may often seem easier as systems of indirect tax collection, already in place in most countries, can be harnessed.

This is however not to say that effective implementation of emissions pricing through carbon taxation is necessarily easy. One problem is that several policy instruments are usually brought to bear on fossil energy consumption, and thus on GHG emissions. Being obliged (say by international treaty) to impose a higher than desired carbon tax, countries may be able to undo parts of the effect of such a tax by manipulating other albeit less well-targeted instruments (such as reduced rates of sales taxation). It can be difficult for an outside party to verify that an effective cost increase for fossil fuels has, all in all, resulted.

The choice of instrument may also have political economy dimensions. Most obviously, there has been a clear tendency to over-compensate producers through generous allocation of free permits—a core issue returned to in Section IV.A below. A cap may be perceived as more firmly based on the science of climate change, so depoliticizing a key fiscal choice. And it

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[30] See Strand (2010b).

[31] See for instance Lucas (2010) and, on other tax issues raised by tradable allowances, Csikós (2007).

[32] A number of administrative issues have also emerged. The EU ETS, for example, created opportunities for "carousel" style VAT fraud. This prompted a variety of unilateral responses, with "reverse charging"— imposing the VAT obligation on the buyer—ultimately adopted.

may be easier to charge consumers higher energy prices through quotas that push up production costs rather than by imposing explicit taxes which appear on utility bills. The cross-country allocation of revenue from carbon pricing may also in practice differ between tax and cap-and-trade systems. Revenue from a carbon tax is commonly presumed to remain in the country that levies the tax, which is taken to be that in which final use occurs. (There is, however, no inherent reason why carbon tax proceeds should be allocated on such a "destination" basis.) Under international cap-and-trade, in contrast, countries where abatement is relatively cheap would sell emission rights to those where it is costly. The extent of the consequent transfers—and hence incentives to join the scheme—depends on how emission rights are allocated. This is explored further below.

C. Rates, Revenue and International Flows

At what level should the carbon price be set?

The technical complexities and judgments required to calculate carbon price paths are reflected in quite widely-varying estimates. One meta-study of estimates of the marginal social damage from carbon emissions[33] finds a modal value of around US$6 per ton of CO_2, and a median—the distribution being strongly right-skewed—of US$15/tCO$_2$. (Tol, 2007). The U.S. Environmental Protection Agency (2010) arrives at a central value—averaged over a range of 'Integrated Assessment Models' (see below) and at a discount rate of 3 percent— of around US $25 per. The Stern Review (2007) estimate, towards the upper end of the distribution, is US$85/tCO2; Nordhaus (2007), on the other hand, suggests a starting carbon price of around US$5/tC. For comparison, the current EU ETS forward price (September 2011; for delivery in December 2011) is around € 12/tCO2.[34] Since the business as usual (BAU) projections from which they derive implicitly reflect current policies, the corrective carbon prices these estimates imply should be seen as additional to existing measures.

These estimates are in some respects only moderately daunting: a charge of US$20 per ton is equivalent to around US$8 per barrel of oil, or 20 cents per gallon of gasoline—well within commonplace fluctuations. For coal, however—which accounts for around 44 percent of all emissions from fossil fuels (compared to 37 percent for gasoline)—this is in the order of a doubling of the price.

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[33] Since carbon pricing would reduce emissions and hence marginal social damage, estimated damage under BAU overstates the corresponding Pigovian charge. Stern (2007), for example, has strong mitigation reducing marginal damage to US$105/tC.

[34] See www.pointcarbon.com

How much revenue is at stake?

To provide a broad and coherent view of possible prices of carbon prices and associated revenues, this section reports results using two widely used 'integrated assessment models':[35] the "IGSM" and "MiniCAM"[36] and estimates in IMF (2008b) using the G-cubed model of McKibbin and Wilcoxen (2002); the latter is similar to the IGSM but explicitly models international capital flows. Results are reported for three stabilization objectives (Figure 1): the most ambitious (450 pm; where concentrations include man-made non-carbon emissions) is widely regarded as effectively unattainable and the highest (650 ppm) as very risky, so the discussion focuses on stabilization at 550 ppm. All these model exercises assume that carbon pricing is globally uniform.

In the IGSM, the carbon price (shown in the lines) rises from about US\$20/tCO_2 to US\$105/tCO_2 (from US\$10 to nearly US\$50 per barrel of oil) by 2060. It is far lower throughout under MiniCAM (note the different scales), mainly because baseline emissions are far less, reaching US\$37/tCO_2 by 2060.[37]

The potential revenue from appropriate carbon pricing is around 1–2 percent of global GDP until mid-century—significant but not transformational. Revenue increases throughout the century (except under the more aggressive MiniCAM scenarios, which achieve stabilization much earlier), with the increasing carbon price more than offsetting any fall in emissions.

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[35] IAMs combine a wide range of economic and physical processes characterizing the human influence on, and interactions with, the global climate (including both mitigation and adaptation). Their strength in the present context is a relatively detailed modeling of energy use and mitigation opportunities. They (especially MiniCAM) are less well-suited than G-cubed, which is an intertemporal general equilibrium model, to modeling investment, savings, and balance of payment effects. An appendix to IMF (2008b) provides a detailed comparison of these and other models.

[36] See, respectively, Paltsev and others (2005) and Brenkert and others (2003).

[37] Note that figures in the tables are given per ton C, which implies that in the tables, the respective prices per ton CO_2 are multiplied by a factor of about 3.6.

Figure 1. Carbon Prices and Global Revenue
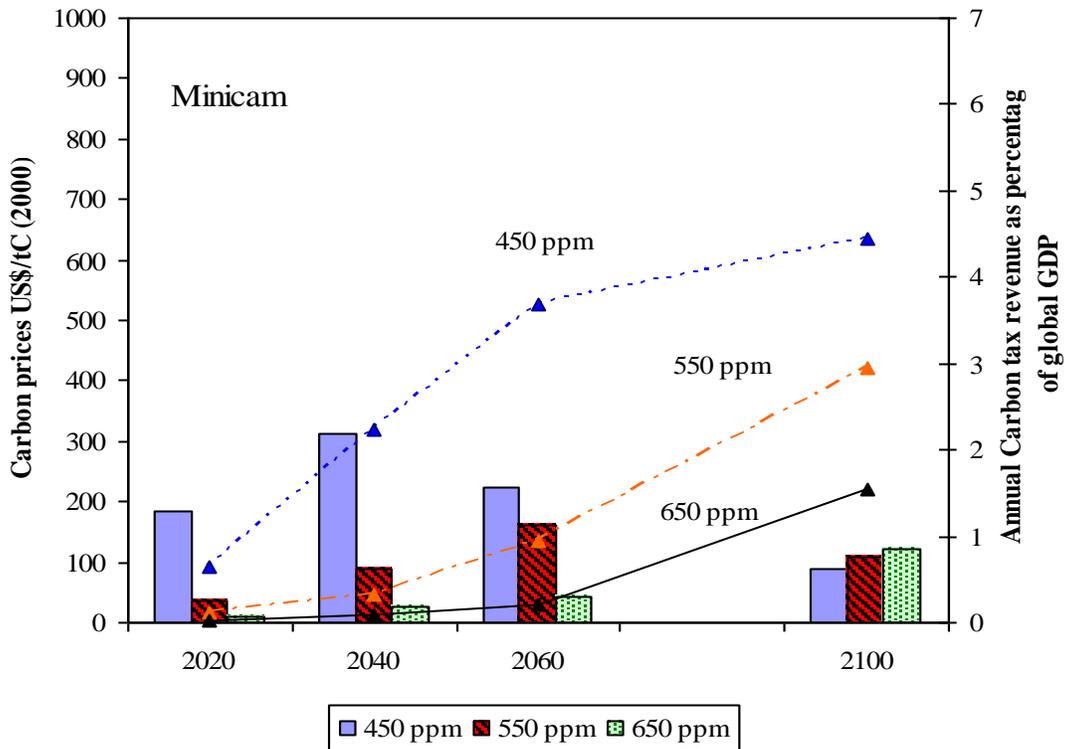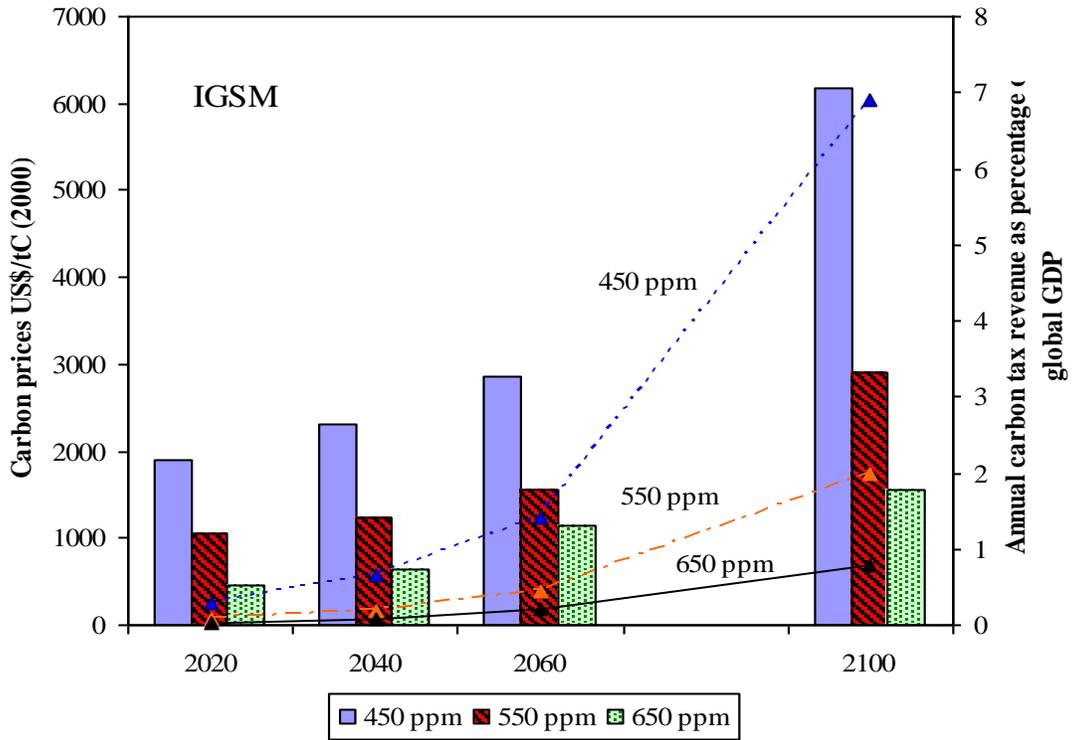
Source: IMF (2008a), using MiniCAM and IGSM output.
1/ Lines represent carbon price (left scale), bars represent revenue in percent of GDP (right scale).

Table 1 reports implied revenue by region in the MiniCAM simulations (such a breakdown not being available for IGSM). The figures are in some cases sizable—a 2 point increase in the tax ratios in Africa, FSU/East Europe and India by 2060 stands out—and would be something like twice as large with carbon prices at IGSM levels.

Table 1. Revenue from Carbon Pricing by Region, Based on the MiniCAM Model
(in percent of GDP)

	450 alternative			550 alternative			650 alternative		
	2020	2060	2100	2020	2060	2100	2020	2060	2100
Africa	2.5	2.9	1.3	0.5	2.2	1.4	0.2	0.6	1.5
China	2.5	1.7	0.6	0.6	1.3	0.7	0.2	0.4	0.8
FSU/East Europe	3.9	1.9	0.2	0.9	2.0	0.6	0.2	0.5	1.0
India	2.6	1.2	0.1	0.6	1.7	0.7	0.2	0.5	1.1
Japan	0.5	0.8	0.4	0.1	0.5	0.4	0.0	0.1	0.2
Latin America	1.2	2.6	1.3	0.2	1.1	1.2	0.1	0.3	1.0
United States	0.9	1.1	0.5	0.2	0.7	0.5	0.1	0.2	0.4
West Europe	0.7	1.0	0.2	0.1	0.8	0.4	0.0	0.2	0.5
Rest of the world	1.7	1.4	0.8	0.5	1.1	0.9	0.2	0.3	1.0

Source: IMF (2008a), using MiniCAM output.

Cross-country flows under international cap-and-trade

International financial flows from cap-and-trade are highly sensitive to the allocation of initial emission rights across countries and could in some cases be sizable. Figures 2 and 3 show financial inflows by region (from MiniCAM) under two illustrative and very different rules for the allocation of such rights. One is simply in proportion to BAU emissions; the other in proportion to population. The latter provides a simple illustration of the important point that the allocation of emissions rights under a global cap-and-trade scheme provides, potentially, a device by which efficient mitigation can be combined with inter-country side payments to encourage participation by developing countries.[38]

In each case—recurrent features in analyses of this issue—Africa and India would be net sellers of permits, and OECD members net buyers. But whereas flows are much less than one percent of GDP with allocation relative to BAU (again, except under the 450 ppm alternative where they are greater), with equal per capita allocation Africa and India have inflows of around 1 percent of GDP in 2020, and rising steadily thereafter for Africa. The results also show that the allocation rules have notably different effects for particular regions: having

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[38] Schemes of 'contraction and convergence' (as analyzed for instance Böhringer and Welsch (2004)) envisage a phased shift from the BAU-based allocation to that based on equal per capita emission rights Here, for sharpness of comparison, there is no transition.

relatively high emissions but a relatively small (and shrinking) population, the Former Soviet Union (FSU), for example, sells permits in one case but buys in the other.

Results are in important respects model-specific. Table 2 reports results using G-cubed, taken from IMF (2008b). Though the exercises underlying the two sets of results are not fully comparable—there are differences, for instance, in BAU projections and regional/country coverage—they are in many respects qualitatively similar, and consistent with others. But

**Figure 2. Financial Inflows from Global Cap-and-Trade,
Allocation by Baseline, 2020–60**
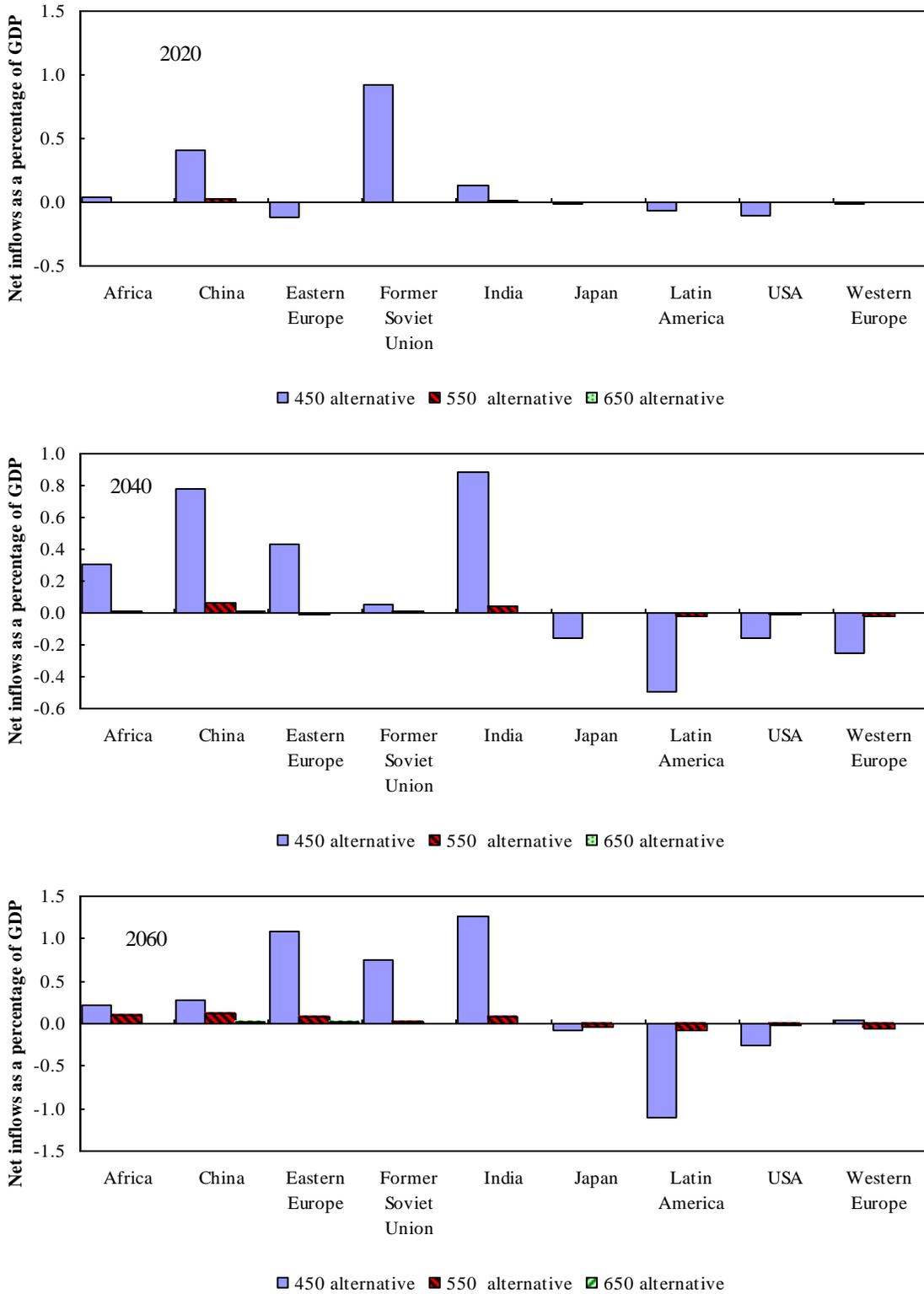
Source: IMF (2008a), using MiniCAM output.

Figure 3. Financial Inflows from Global Cap-and-Trade, Allocation by Population, 2020–60
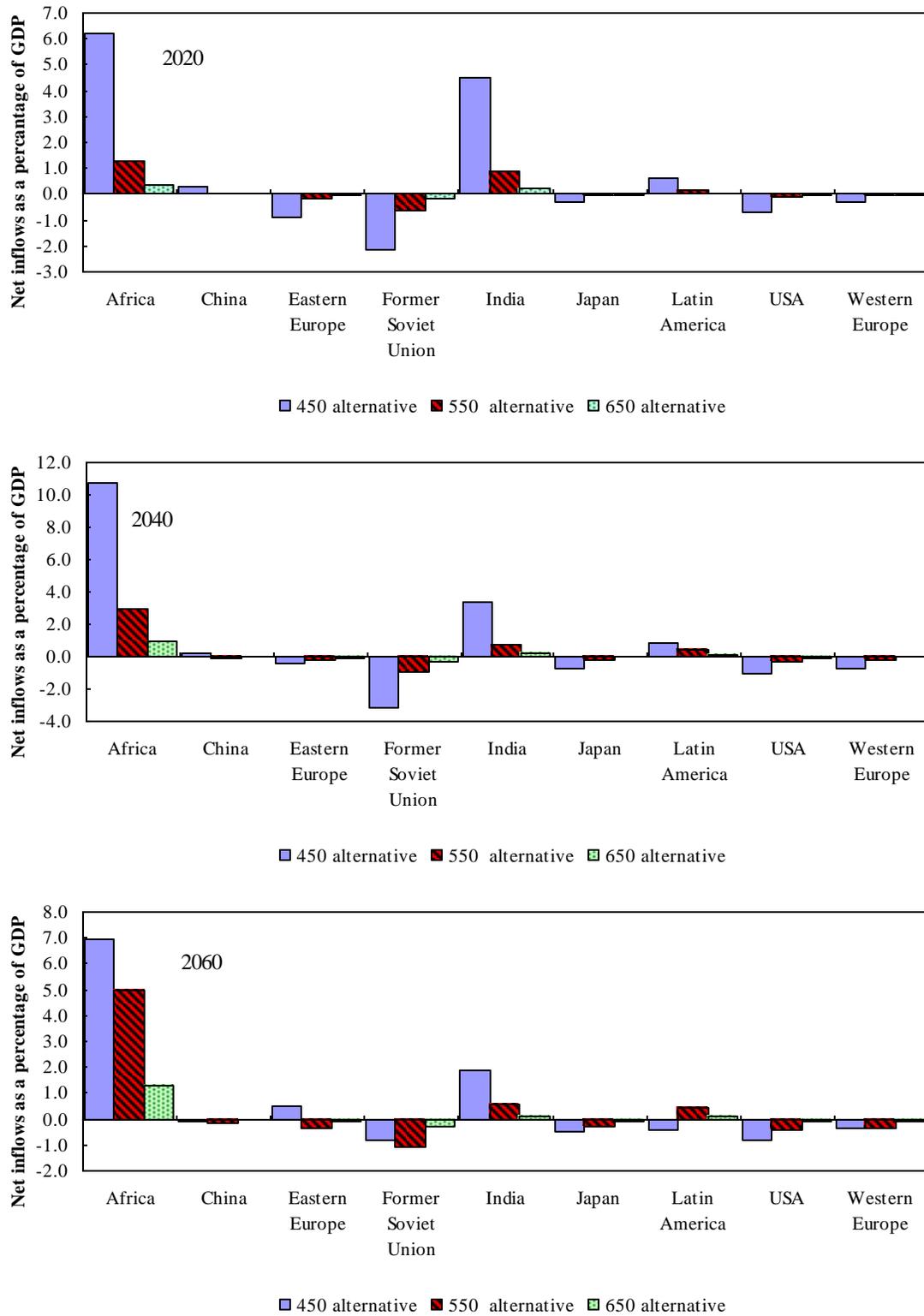
Source: IMF (2008a), using MiniCAM output.

Table 2. International Transfers under Cap-and-Trade, Using G-Cubed[1, 2]
(in percent of GDP)

Region	2020	2030	2040
Annual emission rights proportional to initial emissions[3]			
United States	0.02	0.11	0.22
Japan	0.00	-0.01	-0.04
Europe	0.00	-0.01	-0.03
China	0.32	2.16	5.95
Less developed countries	-0.11	-0.59	-1.44
Eastern Europe and Russia	-0.01	-0.05	-0.12
OPEC	0.08	0.29	0.53
Annual emission rights proportional to population share			
United States	-0.02	-0.32	-0.32
Japan	-0.12	-0.24	-0.35
Europe	-0.12	-0.24	-0.34
China	0.33	1.96	5.46
Less developed countries	0.71	1.08	0.77
Eastern Europe and Russia	0.29	-0.62	-0.87
OPEC	0.51	1.15	1.66

Source: IMF (2008b).

[1] Emissions reduced by 40 percent from 2002 levels.

[2] A positive value denotes receipt of transfers.

[3] This allocation rule differs from that underlying Figures 2 and 3 (which is by emissions throughout the BAU path).

there are also differences. Most notably, China emerges as a modest buyer or seller in Figures 2 and 3 but a large seller in Table 2:[39] Intuitively, China's rapid growth points to a high demand for rights to emit but relatively cheap opportunities for abatement points to a high supply. This calls for great caution in interpreting the results, and stresses the

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[39] The wider literature also reaches divergent conclusions on China's position. Böhringer and Welsch (2004) and the German Advisory Council on Global Change (2003), for instance, have China respectively selling and buying permits.

importance of understanding better the relative ease of mitigation across countries and other drivers of international permit trade.

D. Equity Aspects

Carbon pricing will affect the level and distribution of real incomes both within and across countries.[40]

The degree of pass-through to final consumer prices to a large degree depends on the fuel supply response. If this is relatively inelastic, most of the impact will be on producer prices, and the rents associated with fossil fuel extraction. To that extent, the burden will fall largely on fossil-fuel producing countries. Most of these are of course wealthy countries, but less noticed, and not yet fully integrated into the policy debate, is that, as with recent oil discoveries in Ghana and Uganda, an increasing number of lower income countries are becoming oil producers and so, on this account stand to lose from more effective carbon pricing.

In developed countries, increased fossil fuel prices are likely to have a regressive impact to the extent that they fall on consumers. The impact on U.S. households, for example, of a carbon price around US$50/tC is estimated to be quite strongly regressive,[41] reflecting quite large increases in the prices of electricity and gas (around 12 percent) and gasoline (around 8 percent). However, instruments to offset such effects are commonly available, at a cost less than the additional revenue raised—for example, by reconfiguring the earned income tax credit and social security payments in the US (Metcalf, 2007), or by removing excises on electricity ('wire taxes') that are mandatory in the EU. Other benefits targeted to vulnerable groups, such as the winter supplement to pensioners in the United Kingdom, may also play a role.[42] Compensating measures need to be carefully designed, however: reduced indirect tax rates on energy-intensive products, for instance—such as the lower VAT rate on electricity in the United Kingdom—compromise climate objectives and are poorly targeted on vulnerable groups. Ultimately, the scale of the problem should not be over-stated: the energy price increases at issue are fairly moderate relative to those experienced from market fluctuations in recent years.

Distributional effects are less clear-cut in many developing countries, where the first step towards effective carbon pricing is in many cases eliminating remaining fuel subsidies, both explicit and implicit. Coady and others (2010) suggest that halving energy subsidies in

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[40] And across generations too, as discussed in Section II above.

[41] Hassett, Mathur, and Metcalf (2007) show, however, that, for familiar reasons, regressivity is much less marked when assessed from a lifecycle perspective; and, perhaps more surprisingly, that there is relatively little regional variation in the impact in the U.S.

[42] Dresner and Ekins (2006), however, argue that the wide variation in energy efficiency make it hard to protect all the poorest against increased energy prices in the U.K.

developing countries—which had a revenue cost of around $250 billion in 2010[43]—could reduce greenhouse gas emissions by nearly 5 percent by 2050. Often substantial—17 percent of GDP in Azerbaijan, 13 percent in Iran, and 9 percent in Egypt—petroleum subsidies are an expensive and inefficient way of supporting the poor: fuel and fuel-intensive goods account for a larger share of the spending of the poor, but the rich spend absolutely more on them.[44] More generally, distributional effects will depend on patterns of consumption: the effect through gasoline prices is more likely to be regressive where car ownership is high, and that through kerosene more regressive where its use for household lighting and heating more common. An eye also needs to be kept open for unintended side effects: increasing kerosene prices, for instance, may induce substitution towards burning wood, with adverse implications for both health and deforestation.

Even where tax-benefit systems are relatively weak, there may be better-targeted ways of protecting the poor than by subsidizing energy use. Ghana, for instance, accompanied fuel price increases with the elimination of school fees for primary and secondary education. Outright earmarking of revenues from carbon pricing can be a tempting way to appease opponents, and indeed casual inspection suggests more generally that environmental taxes are more commonly earmarked than are other taxes. One can see reason for that: since the main purpose of environmental taxes is to change behavior rather than raise revenue, pressures arise to compensate the losers and ensure that the proceeds are not spent wastefully—which earmarking can, in principle, do.[45] But earmarking has considerable disadvantages too, If it genuinely constrains expenditure, it almost certainly makes it inefficient and inflexible: the economic rationale, for example, for allocating part of the proceeds from the Clean Development Mechanism (CDM) to an Adaptation Fund is unclear, since there is no link between the appropriate revenue from mitigation and the appropriate spending on adaptation. But if earmarking does not constrain spending, it is essentially an exercise in obfuscation. The question is whether these drawbacks may be a price worth paying if no other way can be found to overcome resistance.

Less studied and largely absent from public debate than effects through consumer prices are the distributional effects from carbon pricing that can also arise on the income side of households' accounts. Fullerton and Monti (2010) emphasize the potential importance of changes in relative wage rates across different segments of the labor market—and suggests

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[43] IEA (2010) estimates global subsidies across all fossil fuels at approximately $550 billion per year: about $300 billion for oil, $200 billion for gas, and $50 billion for coal; about$100 billion is subsidized electricity generation inputs, and the rest direct use subsidies. See also Joint Group Report (2010).

[44] See for instance the review of experience in Coady and others (2006).

[45] See OECD (2006) and Brett and Keen (2000).

that a higher propensity for low-skill workers in the US to be employed in emissions-intensive sectors may raise some distributional concerns.[46]

IV.   ASSESSING AND IMPROVING MITIGATION POLICIES

This section turns to practice: issues in current approaches to carbon pricing, and in fostering international cooperation.

A.   Current Carbon Pricing Policies

Incoherencies

Fully comprehensive carbon tax regimes, uniform across emission and sectors, are very few. The cleanest examples are Australia, which plans such a tax (in transition to a trading scheme) from 2012, Mauritius and British Columbia. Denmark, Norway and Sweden were early actors in the area, though in each case there are significant exemptions. Cap-and-trade schemes are somewhat more common: in New Zealand, the Regional Greenhouse Gas Initiative covering ten U.S. states, and, most extensive, the greenhouse gas Emissions Trading Scheme of the EU (EU-ETS). The last covers only about 45 percent of GHG emissions in the EU region, although its expansion to new sectors including international aviation and gases such as Nitrous Oxides is planned for the next phase.

More widely, however, a wide variety of taxes, generally designed with other considerations more paramount, affect emissions. The most obvious are the excises—or subsidies—on petroleum products (differing from systematic carbon taxation in that they are not calibrated to the varying carbon contents of the various fossil fuels), but there are typically many others. Emissions from transportation, for example, may be affected by the tax treatment of company cars, or by the import duties on cars, progressive in vehicle weight and motor size, common in some European countries (including Denmark and Norway). And regulatory provisions have effects in some respects akin to carbon charging. In fossil fuel producing countries, fiscal arrangements also impact extraction and hence emissions.

The overall picture is often one of considerable incoherence. The recent Mirrlees Review (2011) of the U.K. tax system points out, for instance, that the range of relevant instruments imply an implicit charge per tonne of CO2 that ranges from infinity for nuclear power, through £43 for business use of gas to zero for gas used for domestic heating.[47] And the existence of the EU-ETS can negate the impact of some measures bearing on emissions outside the sector it covers: measures to reduce household use of electricity, for instance, will tend to lower the price power companies are willing to pay for their permits—which will then simply be taken up by other emitters.

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[46] This result rests on assumptions regarding the elasticity of substitution between clean capital and different labor types, which may also vary across countries.

[47] And £250 for petrol, though comparison is questionable as the dominant externality is in this case congestion.

Efforts towards greater coherence in energy tax policies do seem to be gathering momentum in some cases. The EU, for example, has recently (in April 2011) proposed amendments to the Energy Taxation Directive—having extended the framework of minimum excise rates to a broader range of fuels in 2003 (albeit with some notable exemptions)[48]— to shift the base from fuel consumed towards the quantity of emissions produced. But there remains significant scope and need in many countries for taking inventory of the various policy measures for affecting energy use, so as to assess their coherence, transparency, and effectiveness. Excessive complexity often follows when pursuing several objectives with a single instrument. Fuel excises in developed countries, for example, are used not only to raise revenue, but also to correct for congestion and other externalities associated with road use. As technological developments allow more effective congestion pricing, fuel excises could be restructured—and perhaps lowered—so as to focus more sharply on the mitigation objective that they are best suited to serve.

The diversity of fiscal and other instruments of energy policy complicates cross-country comparisons, impeding effective coordination**.** A common policy, such as a minimum carbon tax, would need to recognize measures already in place. But the variety and complexity of these—including differing reliance on regulation—make them hard to compare. Closer international coordination would increase each country's interest in measures adopted by others, so that coordination would be facilitated by greater coherence, simplicity and transparency of fiscal policies towards energy. It may also be facilitated by coordinated data gathering—along the lines of the database on environmentally-related taxes and charges maintained by the OECD and the European Environment Agency[49]—and analytical work to assess implied effective rates of taxation on carbon emissions.

The first step to proper carbon pricing in many countries is to impose appropriate (non-climate related) fossil fuel taxes and equalize them across types when corrected for local externalities. Raising fuel prices is called for, even absent climate concerns, not only in most developing but also in some higher income countries: Parry and Small (2005) conclude, for example, that—given the multiple objectives being served—fuel excises were "too low" in the United States in 2000. Parry and Strand (2011) draw the same conclusion for Chile, despite its having the highest gasoline tax rate in Latin America. Applying the same framework across a broader set of countries, Ley and Boccardo (2010) find that (under the base assumptions) motor fuels are under taxed in six major countries (China, Russia, the U.S., Brazil, Mexico and Canada) which together account for more than 40 percent of total global transport-related GHG emissions. Many tax systems continue to be unduly favorable to diesel.

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[48] Including for electricity used in the production of chemicals and metals (two major polluting sectors). These sectors are however today covered by the EU-ETS and thereby already subject to a carbon emissions price.

[49] Available at http://www2.oecd.org/ecoinst/queries/index.htm.

Not least, fuel used in international aviation and shipping—which collectively account for 6 or 7 percent of global carbon emissions—is essentially uncharged. While carbon pricing is, as ever, the preferred instrument, particular obstacles arise in each case. For international aviation, treaty commitments and bilateral air service agreements may impede effective carbon pricing; ticket; less well targeted ticket taxes may then have a role, also helping address distortions arising from the typical exclusion of international air travel from sales taxation. In international shipping, the extraordinary mobility of the tax base—large ships can travel the world on a single bunker of a fuel—make widespread international cooperation essential for an effective charging scheme, with many developing countries fearing the impact that this would have on them—absence explicit compensation. Keen and Strand (2007) and IMF and World Bank (2011) review these issues and possible solutions.

The importance of auctioning permits

Realizing the fiscal benefits of cap-and-trade requires that rights be purchased by emitters, not allocated to them for free. In the first stage of the EU-ETS, for instance, at least 90 percent of permits were allocated free of charge. Looking forward, while future allocation rules remain subject to some uncertainty, the share of emissions rights to be auctioned under the EU ETS is expected to increase after 2012, to perhaps around 50 percent of the total allocation by 2020 or so (although the industrial sector is expected to continue to receive virtually all permits free at least until 2015). However, overall revenue losses due to incomplete auctioning for EU governments may not diminish substantially, given expected increases in permit values (under a tighter cap) and broader coverage of the scheme. Similar trends appear to be emerging in the United States, where recent draft legislation implied that government effectively would forego $670 billion of the $850 billion in emissions quota value projected for 2011–19.[50]

Allocating free rights in relation to past emissions—'grandfathering'—is of course a way to limit any adverse impact on affected firms: setting the allocated amount equal to historic emissions ensures that the firm can maintain its profit unchanged simply by acting as it did in the absence of the permit requirement. Indeed such an a allocation over-compensates, since by slightly cutting emissions the firm can receive income by selling rights while having no first-order effect on its permit-exclusive profits.[51] Free allocation can thus result in increased profits even if set at a level somewhat below past emissions. And in imperfectly competitive environments, profits can increase still more if the permit system acts as a coordinating device for competing firms to collectively reduce output. Erring on the side of over-compensation by grandfathering allowances may in some cases be reasonable where firms have sunk large investments before emissions charges were thought of. But with the climate debate now far from new, the force of such considerations is now considerably less. Current

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[50] CBO (2009).

[51] Loosely speaking, the gain will be greater the less concave are permit-exclusive profits in emissions; a low elasticity of demand, for instance, is in this respect conducive to larger private gains.

and prospective levels of free allocation likely create windfall profits for firms, and do little to shield consumers from increased prices of energy-intensive products. Burtraw and Palmer (2008), for example, estimate that free transfer of just 6 percent of emissions rights would be sufficient to fully compensate electricity producers for any resulting reductions in their value (although other studies put the figure somewhat higher—perhaps 25–30 percent).[52]

Grandfathering can also cause inefficiencies: when firms expect future free allocations to reflect current emissions they may fail to abate (and sell permits) even when their own abatement costs are below the permits price—and hence, below those of other emitters. Benchmarked updating of free allocations over time—for example, where the allocations are based not on actual emissions from each firm but instead on (hypothetical) emissions given that best-practice technology is—may limit these problems. But this is likely to be administratively complex when compared to auctioning, and has the added disadvantage that auctioning revenue to the government is still foregone.

At a minimum, where grandfathering is politically unavoidable,[53] the value of grandfathered rights should at least be formally recorded as a tax expenditure, opening the issue up to public debate.

Addressing deforestation

Establishing incentives for reduced deforestation--accounting for about 20 percent of emissions, and often presumed to be a particularly cheap form of abatement—remains a priority. This market was outside the scope of the Kyoto Protocol, due to both the conceptual challenges posed and problems in forestry governance. Some progress is now beginning to be made: the World Bank's Forest Carbon Partnership Facility, for example, is providing capacity building support and piloting incentive schemes. The "Copenhagen Accord" of 2009 highlights reduced emissions from deforestation and degradation as central to future international cooperation; Norway, for instance, has pledged $1 billion each in support for reduced deforestation in Indonesia and Brazil.

However, significant carbon market reform is likely to be needed in order to deliver on these objectives. Extending formal emissions trading to forestry markets, for example, or allowing firms to meet their caps through purchase of international deforestation "offsets" could help—subject to the necessary monitoring and verification assurances on the supply side—to mobilize finance for forest preservation in developing countries on a larger scale than could

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[52] The lower figure partly reflects that fact that firms may also benefit from induced growth in other sectors: many utilities, for example, have direct commercial interests in renewables.

[53] Bovenberg, Goulder, and Jacobsen (2008) show that instrument choice may be affected if political economy dictates that firms be compensated: imposing a carbon tax and compensating by lump sum transfers may be inferior to command-and-control measures, for instance, because of the cost of financing those transfers from distortionary taxation.

be achieved from public funds. However, restrictions on the importation of forestry credits are currently anticipated on deforestation offsets on firms regulated under the next phase of the EU ETS. Accelerated efforts to reduce relevant administrative concerns in host countries, and limit any residual risks for example through some (albeit not complete) import restrictions, and/or market segmentation, seem needed.

B. International Coordination

A fully coordinated approach would involve a uniform carbon price in all countries, with cross-country transfers addressing any fairness concerns—but a range of national fiscal concerns impede such a cooperative outcome.[54] Perhaps most fundamentally, a dominant concern in fuel pricing—at the heart of the free-rider problem in relation to implementing climate policy—is each country's fear that unilateral action would disadvantage producers of energy-intensive products (such as aluminum, paper, steel, and international transport) in world markets; a concern exacerbated by the perception that much of the burden of this would fall on developing countries not responsible for the buildup of greenhouse gases. Exporters of fossil fuels have an incentive to resist carbon prices to the extent that these may impact their rents[55] (and, by the same token, an incentive to impose and collect such charges themselves, if they are to be imposed at all). Energy security concerns could point in the same direction, but may relate more to the diversity of supply than to the level of demand.

Incomplete participation in mitigation efforts is likely to result in significant inefficiencies. While emissions are concentrated among relatively few countries—25 account for about 80 percent—wider agreement is likely to be needed for efficient and effective mitigation. The wide inter-country variation in and steepness of marginal mitigation costs suggest a strong efficiency case for "broad-but-shallow" over "narrow-but-deep" agreements: OECD (2009), for example, shows that both the mitigation costs and leakage rates fall rapidly when the scope of any coalition is broadened. Nonetheless, game theoretic analysis in this context—while generally cautious on the overall prospects for a stable and effective international environmental agreement on greenhouse gases controls—suggests that a small coalition of large emitters may offer most promise in this regard.[56] This argue for seeking a deal between the (relatively few) major emitters rather than the universe of countries.

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[54] In the absence of international transfers, it is worth noting, uniform carbon pricing across countries may be not only inequitable (Sandmo, 2005) but Pareto inefficient. This follows from the results of Keen and Wildasin (2004).

[55] Conversely, importers of fossil fuels have a collective incentive to use carbon taxes or tariffs to extract rent from exporters; and exporters have a corresponding incentive to manipulate supply. The net outcome could, in principle, be carbon taxes that, from a global climate perspective, are too high rather than too low (Strand, 2008). Of course, given the likely damage projected under BAU, this is not the dominant effect at work.

[56] This is because the optimal response to defection by one of more parties in the case of a small coalition of large emitters—to substantially reduce their mitigation activity—acts as a stronger deterrent than in the case of a large group (where defection by one country affects the optimal effort of remaining signatories only marginally). See, for example, Bloch (1997), Finus (2001), Finus and Rundshagen (2003), Barrett (2003), Rubio and Ulph (2006, 2008).

The effectiveness of coordination by some subset of countries—and the incentives for unilateral action—depend on the likely extent of 'leakage,' by which is meant the prospect that the effect will be to some degree offset by increased emission by non-participants—whether through relocation of polluting industries or, more important in several studies, in response to reduced world prices of fossil fuels. The potential extent of leakage remains unclear, and available studies are rarely comparable. Some put leakage rates under the Kyoto Protocol in the order of 5-15 percent on average.[57] However, leakage from unilateral or weakly coordinated measures could be much more marked in markets for energy intensive traded goods (such as iron and steel): perhaps 40-50 percent for some US industries.[58]

All this (and practical experience) suggest that some change in the rules of the international negotiations game—beyond expecting simple agreement on an common global carbon price—is needed if real progress is to be made.

Combining international cap and trade with side payments implemented through the permit allocation rules, discussed above, is one such approach. Another has been to search for alternative negotiation frameworks that would provide a mechanism for effective and efficient agreements. Cramton and Stoft (2010), for instance, propose a scheme in which each country proposes a carbon price to be applied by all, the lowest proposed is implemented by all, and each then receives a transfer proportional to the shortfall of its own emissions from the average. Though this does not assure a first-best outcome,[59] it does limit free-riding by providing countries, when choosing what price to bid, assurance that their efforts will be matched by others. Whether it satisfies the participation constraint is less clear: some fossil fuel producers, for instance, may require a zero price to be included in the scheme; which may require that some countries be left out of agreement with significant effect on global emissions. In any event, the advantage of the Cramton-Stoft scheme over other proposed schemes lies in the voluntariness of chosen emissions prices, and that even voluntary prices can lead to substantial global mitigation.

There are other approaches closer to the current policy debate. One standard prescription for responding to downward pressures on low rates from international tax competition—adopted in the EU, for example, for excises—is to adopt not common but minimum rates. This provides some protection for countries wishing to set relatively high rates, potentially

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[57] See Paltsev (2001), and Kuik and Gerlach (2007). Model simulations in Rosendahl and Strand (2011) however indicate that average leakage resulting from CDM projects could be closer to 30 percent.

[58] Fischer and Fox (2007) Ho, Morgenstern, and Shih (2008).

[59] The scheme proposed by Altemeyer-Bartscher, Rübbelke, and Sheshinski (2010) permits efficiency by , considering two negotiators who offer each other take-it-or-leave-it deals on the tax they are to charge and the side-payment to be received; but, unlike the Cramton-Stoft scheme, it is not in general budget neutral.

inducing them to increase their rates by enough to benefit even countries obliged to raise their tax.[60]

Another approach, focused on addressing leakage concerns and potentially encouraging participation, is the use of border tax adjustment (BTA): remitting the carbon price content of exports and imposing corresponding charges on imports. This has the merit of preserving mitigation in respect of domestic consumption without impacting international competitiveness: more formally, Keen and Kotsogiannis (2010) establish conditions under which Pareto-efficient tariff and carbon tax structures require simple BTA of this kind.[61] BTA, moreover, it is one of the few credible devices by which countries implementing carbon pricing can encourage participation by others: participants gain, presumably, from the BTA; and nonparticipants would then benefit by imposing a carbon price themselves, since by doing so they would capture revenue otherwise accruing to others. Not the least of the advantages is that this encouragement of participation comes without explicit side payments, which can be politically problematic, especially when the payments need to go between countries with tense relations. Against this, however, BTA risks hiding tariffs or export subsidies, and may be WTO-inconsistent.[62] It also raises many practical issues, including the need to assess carbon prices implicit in taxes paid abroad (perhaps in a chain of production activities across several countries).

Administrative aspects loom large in reaching international agreements, and may affect instrument choice. Most fundamentally, instruments may differ in their ability to reassure each participating country that others are honoring their obligations. Under a tax scheme, countries would need confidence that others are not offering subsidies or tax breaks that offset the impact of the carbon tax itself. Under a trading scheme, they would need assurance that the governance of permit schemes (including the use made of any quota rents) is sound. Agreement on principles for monitoring, reporting and verification of emissions and mitigation policies and actions has proved particularly contentious in ongoing international negotiations, raising sensitive issues of national sovereignty. Nevertheless, if tax rules are transparent and readily comparable across countries—which may require simplification (or extensive analysis) of energy tax structures, as discussed above, as well as addressing a range of emerging technical issues—carbon taxes might on this account be preferable.

International cooperation on fiscal aspects of mitigation remains extremely limited and flawed, but one can find some encouraging signs. The EU-ETS, for example, has been marred by incomplete coverage, extensive grandfathering and inappropriate entry/exit rules.

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[60] Kanbur, Keen, and van Wijnbergen (1995).

[61] They note too that there is no efficiency case for BTAs when non-participating countries use cap-and-trade, since they then have no impact on emissions there.

[62] McLure (2011) provides an extensive analysis of the legal issues. Ultimately, the issue will remain moot until some case is brought to the WTO.

But it has shown the technical feasibility of international cap-and-trade schemes, at least among closely-related countries; there is perhaps hope of ultimately linking such schemes. Similarly, the Clean Development Mechanism (CDM)—which remains the primary instrument by which the efficiency of mitigation obligations taken on by developing countries may be met by exploiting opportunities for cheap mitigation in lower income countries—has suffered from administrative and, still more fundamentally, conceptual difficulties (Box 2). But it has started to build a framework, short of fully global carbon pricing schemes, for encouraging developing countries' participation in achieving globally efficient mitigation.

Box 2. Carbon Credits and the Clean Development Mechanism (CDM)[63]

Carbon credits enable those subject to emissions restrictions to meet them in part by purchasing emissions reductions from those not so restricted. This is the nature of the CDM, under which support of emissions-reducing projects in lower income countries is creditable against Kyoto commitments. The CDM (with a maximum trading volume of about US$8 billion in primary markets for 2007; which has however dropped and stood at about US$3 billion in 2009) has been the primary means of encouraging mitigation in developing countries. Behind criticisms of the CDM as overly-bureaucratic, now being addressed in part by strengthening programmatic as well as project-based support, lie two fundamental difficulties with offset schemes (which would also apply, for example, to schemes providing payment for avoided deforestation): identifying the baseline relative to which emissions reductions are measured, and ensuring that such reductions are not undone by increases elsewhere (Rosendahl and Strand, 2011).

The prospect of catastrophe, it might be thought, might concentrate minds and facilitate international cooperation. Barrett (2011) shows that his is indeed he case when there is a single, known trigger point for disaster. But this is not so in the more plausible case of multiple and/or unknown thresholds: these effectively 'smooth out' the problem once more, so that the standard enforcement problem remains.[64]

V. FISCAL ASPECTS OF ADAPTATION[65] AND CLIMATE FINANCE

Adaptation to climate change arguably poses much less fundamental fiscal challenges than does mitigation. Much adaptation will occur as spontaneous private sector adjustment in response to (observed and predicted) climate changes.[66] Slow-moving temperature changes

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[63] For further references and discussion, see World Bank (2010).

[64] A further issue stressed in the literature is that the possibilities of catastrophes when GHG concentrations exceed particular levels makes "quick fixes" such as air capture, which could be very expensive, viable options; see Sarewitz and Nelson (2008), Barrett (2009).

[65] Though some aspects of climate change can of course be beneficial, the focus here—the dominant concern in the policy debate—is on harmful effects. (Much the same analysis applies, however, in both cases: both limiting harm and exploiting opportunities, for instance, are likely to be costly at the margin).

[66] Sometimes called 'autonomous' adaptation..

can be expected to generate relatively smooth market responses: ski resorts, for example, will be run down in areas experiencing less snowfall and built up in those experiencing more. Such market responses will have fiscal effects, but, with exceptions, seem unlikely to pose problems more challenging than those from the changing circumstances to which economies are routinely subject. More generally, for developing countries the distinction between adaptation to climate change and development more generally is hazy at best: for example, since agriculture is the main economic sector most vulnerable to climate change, a key way of adapting to climate change is to develop into other activities; and strengthening wider social insurance schemes can improve resilience to extreme weather events, as it does to other traumas.

Indeed some see only a very limited role for government in this area: "National governments and international organizations have little to do with adaptation, and should not try" (Tol, 2005; p.577). Certainly international spillovers and the need for cooperation are not in this case center-stage,[67] and policy responses will reflect national and local differences in wider views as to the proper role of government. Nonetheless, there does arise a potential purposive role for government in traditional functions of providing public goods and addressing market failures.

A. Fiscal Implications of Adaptation—Key Elements

Balancing adaptation and mitigation

Adaptation and mitigation are, by and large, substitutes:[68] the more mitigation is done, the less climate change there is to adapt to. Since each is costly, there is thus a trade-off to be made between them. And, also by and large, mitigation is (or should be) primarily a potential source of government revenue while the most prominent fiscal responses to adaptation—as will be seen—involve additional public spending. How best to make that trade-off thus depends on wider fiscal circumstances: broadly speaking, the greater is government's need for revenue for its wider purposes the more attractive will be using carbon pricing to limit climate damage rather than public spending to adapt to it.[69]

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[67] Some regional or global cooperation may of course be required in some areas: to improve management of water systems, for example, or strengthen regional weather forecasting.

[68] See, in particular, Tol (2005). This is however not always the case—planting mangrove in coastal areas both protects against storms and sequesters carbon, for instance—but is the general tendency.

[69] To see the point more formally, suppose that private welfare is $U(E) + \lambda R - TE - D(E, A)$, where U, strictly increasing and concave, captures the benefits from emissions E, which are taxed at rate T, while R is some item of non-climate-related public spending with λ its relative value, and damages D are strictly increasing and convex in emissions, strictly decreasing and convex in public spending on abatement A and (derivatives denoting subscripts) with $D_{EA} < 0$. When the government optimally chooses both T (and hence , from $U_E(E) = T$, emissions) and A, subject to $TE = A + R$, it is straightforward to show that an increase in λ leads to higher T and lower A.

Given the severe fiscal challenges that many advanced economies face in the coming years, this straightforward point—ultimately about the relative use of taxing and spending instruments—is of some importance. It has seemed easier for governments to launch spending measures addressed to climate change—subsidies for renewables, promises to finance mitigation and adaptation in developing countries—than to deploy revenue-raising instruments to limit it. This tilt of policy, increasingly inappropriate, risks creating significant inefficiency.

Public goods and adaptation

Adaptation potentially requires increased public expenditure both on climate-related public goods and to protect public programs driven by other concerns. Information acquisition and dissemination—on changing precipitation patterns, for example—is one such public good, whose provision requires public intervention (though delivery and some aspects of finance may be left to the private sector). Traditional big ticket items of public expenditure potentially affected include transport networks, water and health systems, and sea defenses. Additional spending will also be needed to protect wider investments, though full 'climate-proofing'—in the sense of removing all effects on some project or activity--is generally not optimal: the investments themselves may need reconsideration, and some residual climate risk accepted.

Uncertainties and irreversibilities require balancing precautionary spending on adaptation against the risk of undertaking costly expenditures that may prove unnecessary. The considerations discussed in Section II.B point to gradualism and flexibility in incurring sunk costs to deal with inherently uncertain climate challenges. This is essentially a matter of project design: for example, in identifying efficient adaptation options for coastal zones (IPCC, 2007). As an example of this 'real options' approach, World Bank (2010) cites dealing with the possibility that aircraft will need longer take-offs in hotter climates not by building now a long enough runway to provide for possible needs but a shorter one combined with an option to purchase additional land as needed. Much of this is essentially common sense—which of course is not so common in practice. The analytical point is simply that where public investments involve heavy sunk costs, the option value of waiting can be high; a point already referred to in Section II above and studied e g by Pindyck (2000).

Fiscal measures to facilitate private sector adaptation

Market failures may impede private adaptation. Private agents may be imperfectly informed (systematic climate change may be hard to infer where the natural climate is variable, for instance); credit market imperfections may hamper adaptation requiring substantial investments; insurance may be unavailable or unaffordable; the Samaritan's dilemma[70] may

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[70] This is the tendency for under-insurance by those who expect external help in the event of adversity: those supplying the help would wish to limit its extent by committing to relatively low support—but their benevolence makes it hard to do so credibly.

lead to inefficiently low adaptation; and the private sector may discount too heavily (so spending too little on projects more robust to longer-term climate developments).

Fiscal instruments, particularly tax measures, may not be the best response to such failures. If the expectation of ex post assistance leads to excessive location in flood-prone areas, for instance, one response is to tax the use of such land. But where administration is weak, zoning regulations, even if less efficient (in denying use even to those willing to pay a proper price) may be more practicable. Other fiscal measures may be tempting but poorly-targeted: tax breaks or subsidies for insurance, for example, reduce public revenue but do not overcome the Samaritan's dilemma.

In some cases, significant barriers to private sector adjustment may themselves arise from ill-designed public policies. Perhaps most notably, the under-pricing of water in many developing countries may not only weaken public finances but impede market signals that would promote effective responses to increasing shortages: World Bank (2010a, p. 91) speaks of "…a clear parallel [between water pricing reform and] the importance for mitigation of pricing reform in the energy sector."

Dealing with fiscal risks

Intervention may be appropriate to facilitate private insurance. Insurance does not reduce the physical damage from climate change (and through moral hazard effects could worsen it). But it can reduce the consequent welfare losses, including by reducing implicit fiscal risks. One response to the Samaritan's dilemma, for instance, is to make purchasing insurance mandatory. In many developing countries, however, market insurance may be unavailable or unaffordable for large groups at actuarially fair rates. There may then be scope for public intervention to provide or facilitate access to risk markets: in Malawi, for instance, the World Bank and donors provide drought insurance.[71]

Recent financial innovations point to new ways of coping with some climate-related fiscal risks.[72] The Caribbean Catastrophe Risk Insurance Facility (CCRIF), for example—bringing together CARICOM countries and launched with donor support in 2007—pays out in the event of parametric trigger points (such as hurricane wind speeds) being exceeded.[73] It is estimated to offer premia about 40 percent below market rates, and provides rapid payment if disaster strikes. The scheme is limited in several respects: verification has proved more contentious than expected, for instance, and pooling among countries subject to correlated shocks limits the benefits from risk-spreading. But it indicates scope for addressing fiscal and other risks from climate change through insurance mechanisms (and is an instance of

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[71] See Syroka and Musifora (2010).

[72] IMF (2008b) provides a more general discussion of the role of financial markets in dealing with climate change.

[73] See http://www.ccrif.org/

effective regional collaboration in addressing adaptation challenges). Potentially even more promising, as tapping more deeply into global capital markets, is the sovereign issue of catastrophe bonds (for which principal is forgiven if disaster strikes); Mexico, for example, issued a $290 million bond of this sort in 2009. Though volumes are down from pre-crisis levels, this is likely to become increasing attractive as the market continues to develop. Whether further innovations could deal with longer-term climate risk, and the uncertainty surrounding some risks, remains an open question (Heal and Kristrom, 2002).

Part of an appropriate response to the likelihood of increased uninsured losses from extreme weather events is increased precautionary public saving. This would convey fiscal benefits not only when disaster strikes but also, through improved ratings and reduced risk premia, when it does not. Given the many other fiscal challenges faced by low-income countries and the possible scale of damage, however, the self-insurance reasonably achievable will often be limited. An important first step—hardly yet begun—is to recognize the fiscal risks involved.

B. How Much?—Assessing the Fiscal Costs of Adaptation

Evidence on the likely aggregate direct public costs of appropriate adaptation measures in general—and fiscal costs in particular—remains scant and patchy, and marked by important uncertainties. But some broad impressions are beginning to emerge.

For advanced economies, two points stand out from the review of estimates for the EU in Osberghaus and Reif (2010). The first is that some elements of warming will ease rather than burden the public finances: through reduced heating bulls for public buildings, for instance, and lower health care costs. The other is that the aggregate costs seem modest: focusing on the upper limits, the implied aggregate cost in mid-century appears to be around €16 billion (in 2005 prices),[74] the main items being flood protection and strengthening transport infrastructures. Uncertainty on some items remains large, however: the cost of flood protection for Western Europe is put at between €137 million and €4 billion.

For developing countries, the most comprehensive analysis is that of the World Bank (2010b). This puts the (undiscounted) aggregate public cost for a 2° temperate rise (over pre-industrial levels) at around $80–90 billion (at 2005 prices) as an annual average from now until 2050,[75] of which perhaps around three-quarters is required before 2020. Infrastructure and water supply expenditures account for roughly one half of these costs; and the adverse impact is greatest for Sub-Saharan Africa. Given limited capacity and resources in many of

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[74] Figure 1 of Obsterghaus and Reif (2010).

[75] This is somewhat higher than previous estimates. An early study by the World Bank (2006) put the cost of climate-proofing existing investments in developing countries at US$10–US$40 billion per annum. UNDP (2007) estimates an annual cost of climate-proofing development investment, by 2015, of around US$44 billion per annum, with an additional US$2 billion to strengthen disaster response—and a further annual US$40 billion in strengthening social safety nets. UNFCCC (2007) estimates suggest an annual investment cost for agriculture, health, water and coastal protection, of around US$40 billion per annum by 2030.

the affected countries, as well as concerns of historical responsibility (and to reduce Samaritan's dilemma issues), they imply need and scope for significant further bi- and multilateral support (as well as private co-financing).

The World Bank (2010b) figures are similar in magnitude to current total overseas development assistance.. In broader terms, however, they are relatively small: for 2010–19, they amount to less than 0.3 percent of GDP in all regions other than Sub-Saharan Africa, where they are around 0.7 percent of GDP. And in all regions they are projected to fall relative to GDP over time. Since the adaptation costs are taken in World Bank (2010b, p.20) to be those "…needed to restore welfare to levels prevailing become climate change", it might seem that the harm from climate change is rather minor. But the assumption of a 2° temperature rise is very modest: and since adaptation costs are likely to be convex in temperature rise, plausible alternatives could give rise to significantly higher numbers. In this respect, these figures are naturally thought of as lower bounds: one reading is precisely that they stress the importance of moderating temperature rise.

Effects will of course vary substantially by geographic circumstance. On sea level rise, for example, Nicholls and Tol (2006) find coastal protection costs (for a rise of around 0.2–0.3 meters over the century) to be less than one percent of GDP annually for the 15 most-affected countries by 2080. In some exposed small islands in the Pacific, however, the figure is notably larger: 5–13.5 percent of GDP in Micronesia, for instance, and 3.9–9.1 percent in Palau. These estimates likely understate total adaptation costs, however, in that they deal only with sustained sea rise at mid-point estimates, and so exclude costs of coping with storm surge and other associated effects, or with more dramatic rise.

Assessing the fiscal challenges from adaptation in developing countries requires a far better understanding of their likely country-specific magnitude. It is currently hard to judge where and when these costs rise to levels of macroeconomic significance relative to the wide variety of other fiscal risks that countries face. A step ahead is recently made through a series of, admittedly preliminary and incomplete, country studies of adaptation costs by the World Bank in conjunction with respective authorities, for Bangladesh, Bolivia, Ethiopia, Ghana, Mozambique, Samoa, and Vietnam, using a variety of tools including both partial and computable general equilibrium analyses.

C. 'Climate Finance'

A strong case can be made, on grounds of both historical responsibility[76] and developmental needs—Stern (2007) and UNDP (2007) stress, for instance, that climate change potentially jeopardizes achievement of the Millennium Development Goals—for developed economies to shoulder a substantial part of the real income loss that mitigation and adaptation are likely

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[76] The argument is made, for instance, in UNDP (2007).

to impose on developing countries. On the latter, signatories to the UNFCCC are explicitly committed to helping "developing countries that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects." More generally, developed countries committed themselves in the Copenhagen Accord and Cancun agreements to mobilize new and additional resources for climate change activities in developing countries of $30 billion for the period 2010-12 and $100 billion per year by 2020, through a Green Climate Fund set up for this purpose, conditional on particular mitigation and adaptation actions by developing countries.[77] Achieving this raises a host of practical issues: precisely how, for example, to define (and monitor) climate finance, and ensure additionality, given the synergies between climate-related and other type of development spending. But the central 'climate finance' question—increasingly prominent in climate negotiations—issue is simply: Where is this money to come from?

How much is to come from private sources and how much from public remains open. To generate the former, credible carbon pricing is again critical for providing signals that will attract private investors. Designing the latter—mobilizing public funds for transfer to lower income countries—arguably has in itself little to do with climate change: if funds must be raised, best advice is simply to use whatever is the most acceptable instrument, whether tax increase or spending reduction available—and that may have no relation to the climate.

Much of the debate, however—taken forward by a U.N. High Level Advisory Group (AGF, 2010) and the World Bank and others (2011)[78]—has nonetheless, been on developing and deploying particular tax instruments to this financing end. Some of the focus has been on developing new tax instruments that in some cases, as with new taxes on the financial sector, bear no very evident relation to climate issues, or on forms on financial engineering. Another theme has been the possible earmarking of revenues from carbon pricing to climate finance; and a third has been to use revenues from charges on international aviation and fuels. Whether allocating the proceeds of these latter charges, however desirable in themselves, away from national governments makes their adoption more or less likely is debatable. In any event, little real progress has yet been made.

The encouraging feature of the climate finance debate is that it provides a framework for delivering the side payments without which, the underlying economics and politics of the problem both suggest, progress will remain painfully hard. It is discouraging, however, that the debate is marked not only by a proclivity for earmarking but some bias towards spending money—or at least promising to spend it—rather than taking firm action now to raise money in ways that help address the underlying climate problem.

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[77] This compares with current bilateral development assistance for mitigation of around $9.4 billion per year in 2008-9, and multi-donor funds with cumulative pledges of around $10 billion (World Bank and others, 2011). Conditions are that developing countries undertake so-called Nationally Appropriate Mitigation Actions (NAMAs), in addition to the adaptation actions to be supported by the Green Climate Fund.

[78] See also Atkinson (2005).

VI. CONCLUDING REMARKS

Climate change is, very largely, a fiscal problem—and to some also a fiscal opportunity. The literature has indeed produced powerful insights, crisp on mitigation and technology policies, helpful—if inevitably fuzzier—on adaptation. It stresses, above all, the importance of comprehensive carbon pricing, at least by the main emitters, as the cornerstone of coherent climate policies. With some exceptions, the impact on practical policy, however, has surely been disappointing. The current agreement, following the Durban meeting of December 2010, to begin in 2015 negotiating a coordinated approach to mitigation, for implementation in 2020, hardly shows the urgency that many have hoped for. It has proved easier to explain the difficulty of effective action in this area than to facilitate it. Perhaps the urgent need for fiscal consolidation in many countries will change things. If not, continued delay will make addressing more radical approaches—developing last-resort technologies or, suggested by Barrett (2006), a focus in designing climate treaties not on mitigation but instead on common efforts to develop new and radical energy technologies, whose development will in case make fossil fuels obsolete—increasingly important.

Appendix 1. The Science and Impact of Climate Change

Average global temperature increases with the atmospheric concentration of greenhouse gases (GHGs). There are three main GHGs (other than water vapor, which is little affected by human activity and decays rapidly):

- Carbon dioxide (CO_2) currently accounts for about 75 percent of GHG emissions; burning fossil fuels—petroleum, coal and natural gas—contributes about 60 percent, and deforestation (which releases carbon stored in soil and forest biomass) 15 percent.[79]
- Methane, mainly from agricultural activity, contributes 15 percent
- Nitrous oxides, generated by industrial and agricultural activities (including nitrogen-based fertilizers) account for most of the remaining 10 percent.

Some man-made factors reduce global warming, most importantly aerosols (particles resulting from sulphur emissions and reflecting sunlight), though these decay relatively quickly and have more localized effects.

The concentration of GHGs in the atmosphere—conventionally measured in parts per million (ppm) of CO_2 equivalent (CO_2e)—has risen from about 280 ppm in 1750 to around 430 ppm now. It is currently rising by more than 2 ppm per annum, and under business as usual (BAU) could increase to around 750 ppm by 2100.

Temperature increases less than linearly with GHG concentration (though climate damage itself is likely convex in the temperature rise). And emissions take some time to have their full temperature effects due to slow heat diffusion processes with oceans.[80] GHG emissions also decay very slowly: emitted carbon stays in the atmosphere for, on average, about 100 years.

By the best current estimate (IPCC, 2007), the global average temperature has increased by about 0.75 degrees Celsius (°C) since 1906 (with the cooling effect of aerosols roughly offsetting the warming effect of GHGs until about 1980). The Intergovernmental Panel on Climate Change (IPCC, 2007) projects that—under current policies ("business as usual," BAU)—the global mean temperature will increase over the next century by 2.8°C, with a 3 percent chance of rising 6°C or more[81] (the latter being roughly the same as the increase since the last ice age).

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[79] Note however that forest biomass used for building materials does not lead to an immediate release of carbon; this occurs only when buildings decay.

[80] Global warming also leads to an increase in ocean water temperatures (which has a feedback effect on land termperatures), but this occurs only very slowly. This implies long lags from an initial climate forcing to a final equilibrium global temperature level.

[81] Relative to average temperatures between 1980–1999.

The physical consequences include changed precipitation patterns, sea level rise (amplified by storm surges), more intense and perhaps frequent extreme weather events, severe impacts on ecosystems, increased prevalence of vector-borne diseases. The potential economic consequences include productivity changes in agriculture and other climate-sensitive sectors, damage to coastal areas from sea level rise and more severe flooding events, stresses on health and water systems, changes in trading patterns and international investment flows, financial market disruption (and innovation), increased vulnerability to sudden adverse shocks, and altered migration patterns—all with potential implications for external stability.

The risk of catastrophic events—shifts in some basic features of the planet's geophysical subsystems—have naturally attracted particular attention, in both public debate and the formal literature. Such possibilities include, for instance, loss of the Greenland ice sheet and a shift of the gulf stream. Little is known about the concentrations thresholds at which these become significant risks; some, even though 'abrupt' in geophysical terms involve transitions of decades or more.

Of course not all of these effects are adverse: agricultural productivity increases in some northern regions, for instance, and opening of the Northern passage; and at least one technically 'catastrophic' event—greening of the Sahara—would convey large benefit. Nonetheless and while views differ on the likely extent of many of these effects, few doubt that they warrant serious and current attention—especially because the worst-affected countries will be those least equipped to deal with them (and with the least historical responsibility for emissions). Assessments of the macroeconomic impact of climate change are reviewed in Jones and others (2007), and IMF (2008b). For a 3°C rise, benchmark estimates for the loss of global GDP range from zero to 3 percent (reflecting differing degrees of coverage of market- and nonmarket effects, the presumed ease of adapting to changing climates, and the treatment of catastrophic risk). Behind these aggregate losses, it is generally agreed that hotter and lower-lying countries—often already the most vulnerable—are most at risk, with some more temperate countries even benefiting from moderate temperature rise. Most of the likely aggregate damage is expected in the latter part of the century. But events such as Hurricane Katrina, the 2002 drought in East Africa and severe floods in Europe, Pakistan and elsewhere—though not simply attributable to climate change—illustrate the possible severity of near-term challenges. Moreover, since core actions to deal with climate change must be anticipatory, policy responses need to be considered far in advance of the damage to be averted. The impact of biofuel subsidies is a stark illustration of the potential for strong current impacts from climate policies (Mercer-Blackman, 2007)

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