CUMULATIVE CARBON EMISSIONS AND CLIMATE CHANGE.

IS THE ECONOMICS LOSING CONTACT WITH THE PHYSICS?

John Rhys. September 2012

SUMMARY

Carbon dioxide (CO2) emissions are essentially cumulative in the earth's atmosphere. The thesis of this paper is that much economic analysis and policy making in relation to the mitigation of CO_2 emissions has failed to reflect fully this essential element of the science.

In particular the cumulative and irreversible nature of CO_2 necessarily implies that a significantly heavier weight should attach to current as opposed to future emissions. This is in major contrast to some conventional wisdom and also to the outcomes and expectations that can be observed from current application of market-based approaches to limiting carbon emissions. Application of a progressive tightening of "carbon caps" – limits on total CO_2 emissions - has tended to deliver a very different message on the relative importance of present and future emissions, with the price of current emissions being very low, but with a prospect of rapid rises in the future.

This inconsistency in time profiles, between a focus on costs or externalities – the social cost of carbon (SCC), and the market price outcome from an emissions cap approach, has the potential to create major distortions in policy and is likely to have seriously sub-optimal results. Similar criticisms could be levelled at policies focused too closely on individual year targets rather than cumulative emissions. Policy making needs to redress this imbalance. Recognition of the cumulative nature of CO2 should strengthen the case for urgency and also lead to more recognition of the option value of early action on emissions.

Some of the implications of these straightforward principles are of direct and compelling importance in relation to major policy issues, such as gas for coal substitution in the power sector, the inclusion of aviation within the EU ETS, and the choice of carbon capture and storage technologies. At a minimum the implications need to be better reflected in guidance on the valuation of emissions for public policy purposes.

INTRODUCTION. THE CUMULATIVE NATURE OF CO2 EMISSIONS

This paper argues the case that much policy making, globally and nationally, pays insufficient attention to some of the fundamentals of climate science, and   in particular to the phenomenon of greenhouse gases (GHG) as agents of radiative forcing (the greenhouse effect).   There are just two basic points. The first is that it is the level of concentration in the atmosphere, *not* the current level of emissions, that determines the extent of the warming effect from their presence in the atmosphere. In other words it is the cumulative effect of past emissions from all sources that matters – the stock of CO_2 rather than the flow.

The second point is sometimes less well understood. It is that man-made emissions of the most important of these gases, carbon dioxide (CO_2), should be regarded, for the purpose of evaluating climate impact, as almost wholly cumulative, in that very little of any incremental emissions of CO_2 are re-absorbed. This hypothesis needs to be stated much more carefully, not least because it is a central feature of the claim that anthropogenic emissions do indeed give rise to a high risk of global warming, and is central to any argument for early action.

At one level this is a simple matter of fact: in the laboratory CO_2 does not react or break down in air, and does not have the equivalent of a radioactive half-life. In that sense its presence in air is purely cumulative. However we are much less interested in the laboratory behaviour of CO_2 than in what happens within the context of natural carbon cycles which involve very large natural transfers of CO_2 to and from the atmosphere every year, the largest being transfers to/from plant life and to/from the oceans. Our concern should be with the cumulative impact of man-made CO_2 emissions on future CO_2 concentration levels, within this context.

The volumes of transfers each year, in both directions, between the atmosphere and oceanic and terrestrial sinks, are much larger than the current levels of man-made emissions. However if anthropogenic emissions were to have no effect on the exchanges in this "natural" carbon cycle, then they would be purely cumulative; although annual emissions may be small, the cumulative amount over decades will be large. If on the other hand the injection of this additional CO_2 does affect the carbon cycles, through climatic or other effects which increase or reduce the carbon cycle exchanges, then the impact of man-made emissions may be less than or more than wholly cumulative. This question is central to all attempts at estimating the overall impact of man-made emissions on climate. If CO_2 emissions were not essentially cumulative then it would be significantly less probable that their climate change consequences were irreversible and it is much less likely that climate models would substantiate the arguments for action to limit anthropogenic emissions.

This paper is not intended to address the science. It merely observes that the current underpinnings of the climate science and policy consensus do indeed treat man-made emissions as essentially cumulative[1]. Conventional assumptions appear to put net re-absorption at very low levels of around 1% pa, but it is recognised that interference with natural carbon cycles might reduce re-absorption to much lower rates or, in worst case scenarios, create a positive feedback of negative re-absorption. There are studies[2] that suggest "... that the terrestrial biosphere will become a less effective net sink of carbon, and may even become a source." In other words an incremental tonne of CO_2 emitted might result, over time, in more than one additional tonne of CO_2 in the atmosphere. It is therefore legitimate, if we treat emissions policy as a response to a real and serious problem, and from a perspective that takes the mainstream science as its fundamental justification, to regard CO2 as essentially cumulative, at least as a first approximation.

One important corollary of this second hypothesis, on the essentially cumulative nature of man-made CO_2, is that the damage caused by present emissions, those for (say) this year, will tend to be greater than that from future emissions, eg those in five years time. This is easily demonstrated[3] by comparison of year after year costs of a given volume of CO_2 that persists; the damage caused by its presence in any given year is independent of the year in which it was emitted. Recognition both of the cumulative nature of CO_2 and of

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[1] Fuller discussion on this topic can be found in the author's earlier paper. *Cumulative Carbon Emissions And Climate Change: Has The Economics Of Climate Policies Lost Contact With The Physics?*, John Rhys, OIES Working Paper EV 57, July 2011. Fuller discussion on this topic can be found in the author's earlier paper.

[2] *Climate-carbon cycle feedbacks under stabilization: uncertainty and observational constraints.* Jones, C.D., P.M. Cox and C. Huntingford (2006). . Tellus Series B. Chemical and Physical Meteorology. 22 September 2006.

[3] A mathematical presentation of this intuitively simple argument is given in the Annex to this paper.

this corollary is confirmed explicitly in at least one integrated assessment modelling exercise, using the PAGE model, and described in a 2005 AEA Technology report.[4] The PAGE model provided the basis for the 2007 UK official position[5] on the social cost of carbon, set out by DEFRA. It was given particular prominence in the economic modelling chosen to conduct analysis within the Stern review[6], and has been described by Hope[7]. This modelling shows a time profile for the social cost of carbon (SCC), discounted back to the common base year 2000*,* falling by about 1% per annum. Appendix 3 of the AEA report shows an SCC value falling from £ 61 in 2010 to £ 55 in 2020 ***after discounting to the common base year***.

The authors of the AEA report were also at pains to point out that this result does ***not hold*** for another important greenhouse gas – methane. The authors state this contrasting result for methane as follows. *"Indeed, the SC discounted to 2000 actually rises over time. This is because of the short atmospheric lifetime of methane; any methane emitted today will have disappeared from the atmosphere before the most severe climate change impacts start. This implies that given a choice today between emitting 1 tonne of methane now, or at some time up to 60 years in the future, we should opt to emit it now."* In other words there is a very clear contrast with the cumulative nature of CO_2.

Our corollary on the additional weight attaching to early emissions, although clearly supported by the report's observations, does not depend on any particular set of models or valuations. It is just a simple logical consequence of the cumulative nature of CO_2.

Implicitly this reinforces the economic arguments for urgency in tackling emissions as a critical element of climate policy. This can be contrasted with a number of observations on current policies, first if these place excessive focus on single year targets, and second where they rely on market mechanisms which currently deliver a very different set of expectations on carbon pricing.

PARADOXICAL CONSEQUENCES FOR EMISSIONS POLICIES

To demonstrate why this matters for emissions policies and targets, it is useful to consider the following simple paradox of how a policy failure can be derived from contemporary targets and the assumption of a carbon prices that attach a higher cost to later emissions. (This will be true if assumed prices are rising faster than the discount rate.)

Suppose I have a large store containing thousands of tonnes of CO_2, held under pressure in large corroding metal vessels. Technical experts have advised me that there is no means of permanently sealing the vessels, other than at prohibitive cost, but that I can with only modest expense treat the seals of the vessels in a way that will prolong their expected life from 6 months to 20 or 30 years, at which point there will be a slow leakage into the atmosphere, perhaps over a 10 year period. What should I do, given an objective of minimising adverse climate impact?

[4] *The Social Costs of Carbon (SCC) Review –Methodological Approaches for Using SCC Estimates in Policy. Assessment. Final Report.* Paul Watkiss with contributions from David Anthoff, Tom Downing, Cameron Hepburn, Chris Hope, Alistair Hunt, and Richard Tol. AEA Technology Environment UK. December 2005.

[5] *The Social Cost Of Carbon And The Shadow Price Of Carbon. What They Are And How To Use Them In Economic Appraisal In The UK.* December 2007. Economics Group, DEFRA.

[6] *Stern Review on the Economics of Climate Change*. HM Treasury. October 2006. Chapter 6.

[7] *The marginal impacts of CO2, CH4 and SF6 emissions*, C Hope, Judge Institute of Management Research Paper No.2003/10, Cambridge, UK, University of Cambridge, Judge Institute of Management.

<u>Answer</u>. Working from a measure or price signal – such as a rising carbon price – that suggests later emissions are significantly more damaging, the answer seems obvious. We should be prepared to spend money not on reinforcing the vessels, but on breaking them open immediately, since the social cost will be significantly higher in five years and even more so in 30 years. Moreover, immediate release would additionally make it easier to meet annual emissions targets for future years.

This is clearly absurd if limiting the CO_2 stock is the real target, and if CO_2 emissions are essentially cumulative. Immediate release, using PAGE estimates of the social costs merely to illustrate the point, should be assumed to be some 20–30 per cent more damaging.

In addition, simple reliance on a PAGE or similar calculus ignores the possibility that a novel low-cost technical solution will be developed for the problem of sealing the corroding tank. There is therefore an additional option value which attaches to not releasing the CO_2, but this value is not captured in a simple social cost of carbon analysis.

This is obviously a hypothetical construct, although in a future that includes carbon capture it is quite credible that closely analogous situations involving storage would arise. But it is a useful parable to illustrate how ignoring the basics of CO_2 science could lead to perverse policy outcomes.

We now move on to the policy implications of recognising explicitly that cumulative CO_2 , not annual emissions, is the issue. These are discussed briefly in the next three sections:

- Implications for global and national target setting
- Price signals in relation to policy, especially where markets are expected to deliver required policy outcomes.
- The option value of early action.

SETTING GLOBAL TARGETS AND NATIONAL POLICIES

Economists generally assume, correctly, that if regulation or policy targets the wrong indicator, for example the volume of inputs rather than the value of outputs as a business growth objective, then the results are likely to be disappointing or perverse. This is a truism in critiques of Soviet planning , where quantity targets unrelated to value are said to have been taken to extremes. A famous cartoon had[8] a crane holding a single multi-tonne nail. The plant manager exclaims: 'Look! This month's output!' – the target for the supply of nails had been set in terms of weight.

A first requirement of CO_2 targets therefore is to align with the objective. This is to minimise or at least limit cumulative emissions(stocks), not to achieve a particular level (flow) by a given date. Targets for annual emissions may be useful indicators, as "headline" statements of requirements but should not obscure the primary objective, of keeping ***cumulative*** emissions within "safe" limits.

From a global perspective, larger early reductions, if they can be achieved and sustained, are disproportionately beneficial in reducing cumulative emissions, and hence in delaying adverse climate impacts. As an immediate consequence they have a large and additional option value in "buying time" both

[8] Allegedlyfrom *Krokodil* . Unfortunately the original has not so far been traced.

to allow a wider range of CO_2 mitigation technologies to be developed , and to allow more time for adaptation to climate change consequences that cannot be avoided.

In principle this is an obvious point but the scale of its importance is surprising. To illustrate the point we consider an 80 % reduction from 2010 over a 40 year period[9] (by 2050) which corresponds to a proportionately constant 3.85 % per annum reduction over the period. If we hypothesise alternative paths that are front-end or back-end loaded, perhaps 1.5 to 2 % higher or lower initially for the first 20 years, and then at a constant rate that gives the same final year emissions, we note some dramatic differences.

Thus even compared to a constant rate of reduction, front-end loading delivers a contribution to cumulative CO_2 that is more than 15 % lower and corresponds to about 15 years of emissions at the achieved 2050 annual rate. One interpretation of this arithmetic would be to argue that some climate milestones, in terms of increased concentration levels, would be reached 15 years later under front-end loading, implying substantially more time to initiate additional measures including adaptation. Back-end loading has correspondingly negative consequences of similar magnitude, implying an immense difference in outcomes if one compares back-end directly with front-end loading.

The point of the above is simply to demonstrate that there are large and important differences between different time profiles for emissions reduction, which are not captured at all by final year targets, and may not be captured adequately even by intermediate medium term targets. Putting appropriate valuations on these differences in CO2 concentration outcomes leads to a further accentuation of the differences, and enhances the benefit of front-end loading.

Early action has a potentially very large “option value”, implicit in buying time and expanding the range of future policy options to deal with climate issues, whether in mitigation or adaptation.

<u>International negotiation. National targets</u>

The undeniable primacy of cumulative emissions as the right measure of performance in abating CO2 concentration implies that a rational approach to the design of an international regime and associated market mechanisms must also be based on cumulative emissions from a baseline, with carryover of emission rights/savings between time periods, and certainly not on rigid annual numbers.

Essentially this point was argued by Myles Allen, then Head of Climate Dynamics, Department of Physics, University of Oxford, both in a 2009 interview with the FT[10] and in an April 2009 paper[11] in Nature.

Allen believes the current approach to tackling climate change is ill-conceived. His latest paper, published earlier this year in Nature, argues we should be looking at the total amount of carbon that humankind emits, not the rate at which we do so – the measure the negotiators in Copenhagen will be focusing on.

[9] This number is chosen, purely as an illustration, to correspond to the actual UK target, but the implicit context is global.
[10] http://www.ft.com/cms/s/2/f1d9f856-d4ad-11de-a935-00144feabdc0.html#ixzz1HFgW1zay provides a link to the relevant FT feature article.

[11] **http://www.nature.com/climate/2009/0905/full/climate.2009.38.html.** *The Exit Strategy*. Myles Allen, David Frame, Katja Frieler, William Hare, Chris Huntingford, Chris Jones, Reto Knutti, Jason Lowe, Malte Meinshausen, Nicolai Meinshausen & Sarah Raper. Published online: 30 April 2009

He shows me a graph with three different curves representing the same amount of carbon being emitted over different timescales. "Temperature response is identical," he says. "It's much easier to frame the problem if you say 'what's the total amount of carbon we can afford to inject into the atmosphere' rather than what concentration should we be aiming for." Yet because of the way the Rio Earth summit and Kyoto Protocol configured the problem, negotiations at Copenhagen are heading in the wrong direction.

These are the considerations that should permeate into the structure of negotiations over how any given burden of emissions reduction should be shared. Their importance is accentuated and reinforced by issues of monitoring and enforceability. There are of course many other considerations that impact on real world negotiation, but it is not necessary to detail these in order to note that issues of fairness, rational incentive structures, and monitoring, all point to the need to base global solutions, in principle at least, on approaches that stress cumulative emissions rather than arbitrary single year targets.

Aligning national or bloc targets to be consistent with the shape and structure of an agreed cumulative aggregate number would be an essential part of a global strategy seeking to contain atmospheric concentration of CO2. The UK at least recognises this to some degree through intermediate targets and period- based carbon budgets which implicitly allow some movement of emissions between calendar years.

GETTING THE RIGHT PRICE SIGNALS

The market approach, unsurprisingly since it is the basis for the EU ETS, dominates most discussion of investment and other commercial decisions in the energy sector, while the influence of the SCC approach, such as it is, is confined to issues of policy concerning the public sector, regulation and other non-market interventions such as innovation policy. One justification for this is the belief that a "market price" approach, subject to suitable reforms of energy markets, will in the long run deliver the necessary levels of new low carbon investment, particularly in the crucially important power sector. This investment would then have been achieved at lower cost to final consumers and perhaps with less risk of windfall profits to existing low carbon producers. These are persuasive but not conclusive arguments in an investment context, since there will inevitably be some investment decisions which will change as a result of a different view of the time profile of CO_2 prices.

The guidance offered by the UK Treasury on carbon valuation in the context of public sector projects and policies is particularly interesting. Emissions, it is proposed, should be valued on different bases according to whether they are deemed to be in the "carbon traded" sector (basically sectors covered by the EU ETS), or the "non-traded" sector.[12] Prices in the "carbon traded" sector are substantially lower for the short and medium term than those in the non-traded sector. Attempting such a separation between sectors or markets creates problems for effective policy making, of "leakage" or informal arbitrage between sectors. One anomalous result of this separation, which puts much lower values on CO_2 in the traded sector, would be to value biofuel more highly as road transport than as aviation fuel, even though the opposite position is prima facie preferable in policy terms.

[12] This is discussed in more detail in *Comments on October 2011 Guidance Issued by Treasury on Valuation of Greenhouse Gas Emission,* published as an OIES Energy Comment in March 2012. Link: http://www.oxfordenergy.org/2012/03/comments-on-october-2011-guidance-issued-by-treasury-on-valuation-of-greenhouse-gas-emissions/

The Treasury is of course able to justify this distinction on the grounds that putting values on UK CO_2 emissions in the “traded sector” higher than those emerging, or expected to emerge, from the EU ETS could have the effect of simply exporting UK emissions.

However the most significant problem resides in assumptions that are currently made about the market price of carbon, primarily determined within the EU ETS. There are many commercial decisions within the energy sector, including decisions on operational and investment, which would be affected by the much stronger signals of a carbon price that correctly reflected a higher and front-end loaded SCC, as compared to the current reality of a low but possibly rising market price of CO_2 emissions.

Apart from the obvious influence of a higher SCC, in reinforcing the case for regulatory or other measures to secure “easy” gains for energy efficiency and conservation measures, the “low hanging fruit”, there are at least two other obvious examples where the weight attaching to relative carbon emissions, and also the time profile, might be expected to have a significant impact, not just on investment but on operational decisions.

A first is in the context of fuel substitution in the power sector. Recognition of the value of early reductions in CO_2 would encourage earlier rather than later substitution of gas for coal in power generation. In global terms, this is a significant short term source of CO_2 reduction, often involving little or no additional investment. Although this is in part a purely commercial decision for generators responding to visible price signals, it is also sometimes seen as a matter for public policy when other factors such as security and diversity of supply are involved. Moreover fuel substitution is a relatively low cost CO_2 abatement option, often with relatively modest investment costs.

A second is in the context of carbon capture and storage. The balance between profiles involving early or later emissions is potentially a major consideration in relation to a number of investment, design and operating choices both for generating plant and for the storage infrastructure. Obvious examples can be constructed in relation to choice between technologies or modes of operation involving different rates of CO_2 capture, and in relation to the security of storage. If this is so, then there should be a clear benefit to those choices being informed by price and cost signals that reflect the physical realities of CO_2 emissions.

OPTION VALUES

Modern approaches to decision theory, and “real options theory” , embody the principle that a positive value can attach to the deferring of a decision until more information is available. To summarise the approach[13], an investment decision can be treated as the exercising of an option. If an investment is irreversible (a sunk cost), then there is an opportunity cost attaching to an investment made now rather than waiting. The greater the uncertainty, the greater is the value of the firm’s options to invest, and the greater is the incentive to keep those options open.

In the context of climate change policy it is often assumed that uncertainty implies that the most appropriate response is to postpone policy actions pending better information, in other words that an option value of delay attaches to doing nothing. However this is little more than a verbal sleight of hand. Large actual investments will be made within the alternative scenarios of policy action and policy inaction. One of the guiding principles of real options theory however is the idea that it is the feature of irreversibility that attaches a high cost to taking a particular course of action now, as opposed to waiting.

[13] *Investment under Uncertainty,* Dixit, A.K. and Pindyck, R.S. 1994. Princeton, NJ: Princeton University Press.

A consequence of the earlier analysis of the science consensus is that, in the context of potential responses to CO2 and climate issues, it is the policy of inaction that results, through the cumulative effect of CO2, in irreversibility, since it is inaction that results in the greater release of CO2. This is illustrated very well by the example of the "leaking tank", where deferring release allows for the possible development of a permanent solution. It is also illustrated by the observation that front end loading of emission reductions will postpone the CO_2 emission or climate milestones at which particular concentrations are reached and particular impacts occur, allowing more time to develop additional measures to mitigate or adapt. Hence one might assume a presumption in favour of early policy action as having a positive option value. This observation further increases the differential that should apply between early and later emissions reductions.

CONCLUSIONS

The analysis above has confirmed the cumulative nature of anthropogenic CO_2 as an integral element in the consensus science underpinning policies seeking to limit greenhouse gases and climate change. This carries the important corollary that, in principle, a heavier weight should attach to current and near term emissions than to emissions in 10, 20 or 30 years time.

This stands at variance with a number of features of current policy and comment, in particular:

- the inability to focus policy and negotiation on cumulative measures at a global level, a failure that has been highlighted by scientists but is not widely recognised .
- inconsistency between the expected profile of "market determined" CO_2 prices and that of the profile of damage and the externalities of environmental and other costs associated with emissions.
- a misleading presentation of the basis for current emissions policy
- justification of policy inaction on the basis of a "wait and see" approach

Early emissions are more damaging because emissions are cumulative and hence early emissions are around for longer; corresponding to this, early measures to reduce emissions are of more benefit than later measures. This should lead us to the following general conclusions:

- Cumulative emissions, ie stocks, are the proper focus of policy, not annual emissions (flows); this needs more explicit recognition in an international context.
- The profile of emissions reduction can have a very large impact on cumulative CO_2 at any given future date, with a consequential impact for the policy options that will then be available.
- Although many critical strategies to secure long term low carbon investment are based on a gradualist approach of increasing market prices, there are strong arguments for seeking to ensure that an SCC based approach needs to be reflected into policy choices relating to fuel substitution; inter alia this tends to reinforce the case for early substitution of gas for coal and might become very significant in relation to carbon capture and storage.
- Early savings not only have a higher beneficial impact; they also "buy time" and can be considered to have an additional and substantial option value; this contradicts the common argument that it is always delay, to gain further information, that has a positive option value. It is early action that delivers option value in the context of climate policy.

ANNEX. INTERPRETING THE SCIENCE OF CO_2 AND CLIMATE IMPACTS

This annex expands two of the points already covered briefly in the main text. First we consider more fully the phenomenon of re-absorption within the carbon cycle. Second a mathematical presentation illustrates the argument that the cumulative nature of CO_2 implies a higher cost attaching to current emissions.

1. Re-absorption of CO_2 within the Carbon Cycle

CO_2 does not decay, react or break down in air. Under laboratory conditions its appears as purely cumulative. However what matters is the additive effect of ***incremental*** CO_2 emissions on future CO_2 concentration levels within the earth's atmosphere. This needs to take into account the actual re-absorption of CO_2 from the atmosphere into oceanic or terrestrial sinks.

This subject is discussed in some depth in Chapter 8 of the Stern Review.[14]

Weakening of Natural Land-Carbon Sinks: Initially, higher levels of carbon dioxide in the atmosphere will act as a fertiliser for plants, increasing forest growth and the amount of carbon absorbed by the land. A warmer climate will increasingly offset this effect through an increase in plant and soil respiration (increasing release of carbon from the land). Recent modelling suggests that net absorption may initially increase because of the carbon fertilisation effects.... But, by the end of this century it will reduce significantly as a result of increased respiration and limits to plant growth (nutrient and water availability).

Weakening of Natural Ocean-Carbon Sinks: The amount of carbon dioxide absorbed by the oceans is likely to weaken in the future through a number of chemical, biological and physical changes. For example, chemical uptake processes may be exhausted, warming surface waters will reduce the rate of absorption and CO_2 *absorbing organisms are likely to be damaged by ocean acidification. Most carbon cycle models agree that climate change will weaken the ocean sink, but suggest that this would be a smaller effect than the weakening of the land sink.*

Re-absorption occurs within a context of natural carbon cycles with very large natural transfers of CO_2 to and from the atmosphere every year, the largest being transfers to/from plant life and to/from the oceans. Moreover these transfer processes are themselves affected both by general and specific aspects of climate, by temperature and by the prevailing atmospheric concentration level of CO_2. In other words the actual re-absorption rate is endogenously determined within the climatic system and can therefore only be stated within a particular context; over time the strength of these processes may alter as changes in climate take place. For example some terrestrial and oceanic carbon sinks may become CO_2 saturated, with a cumulative absorption limit that depends on a variety of climatic and other factors.

These two fundamental features, the endogeneity of carbon re-absorption, and the fact we should be concerned with the incremental effect of extra emissions rather than the fate of a particular molecule of CO_2, have not hitherto been well explained in much of the climate literature. This has led to quotation of

[14] *Stern Review on the Economics of Climate Change*. HM Treasury. October 2006.

some confusing and potentially misleading figures to describe the life of CO_2 in the atmosphere. This is very well expressed in a 2008 article in Nature[15]:

It doesn't help, though, that past reports from the UN panel of climate experts have made misleading statements about the lifetime of CO_2 ..... The first assessment report, in 1990, said that CO_2's lifetime is 50 to 200 years. The reports in 1995 and 2001 revised this down to 5 to 200 years. Because the oceans suck up huge amounts of the gas each year, the average CO_2 molecule does spend about 5 years in the atmosphere. But the oceans also release much of that CO_2 back to the air, such that man-made emissions keep the atmosphere's CO_2 levels elevated for millennia. ....

Earlier reports from the panel did include caveats such as "No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes." The IPCC's latest assessment, however, avoids the problems of earlier reports by including similar caveats while simply refusing to give a numeric estimate of the lifetime for carbon dioxide. Contributing author Richard Betts of the UK Met Office Hadley Centre says the panel made this change in recognition of the fact that "the lifetime estimates cited in previous reports had been potentially misleading, or at least open to misinterpretation."

Instead of pinning an absolute value on the atmospheric lifetime of CO_2, the 2007 report describes its gradual dissipation over time, saying, "About 50% of a CO_2 increase will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries. The remaining 20% may stay in the atmosphere for many thousands of years." But if cumulative emissions are high, the portion remaining in the atmosphere could be higher than this, models suggest.

Other papers have suggested that increasing CO_2 concentration, and its associated climate effects, may have an adverse effect on the carbon cycle and in particular on the ability of certain sinks to absorb more carbon. Stern quotes a recent study[16] to warn that, if feedbacks between the climate and carbon cycle are included in a climate model, the resulting weakening of natural carbon absorption means that allowable cumulative emissions consistent with stabilisation are dramatically reduced.

Actual re-absorption depends on a wide range of factors, and will change over time with the state of other climate and climate system variables. For example one feature of terrestrial and oceanic carbon sinks is that they may become saturated, but their cumulative absorption limit is likely to depend on a variety of climatic and other factors, and will not necessarily be driven directly by CO_2 concentration levels.

It is not meaningful therefore to state a simple mathematical relationship between CO_2 , re-absorption rates and concentration levels. Overall current scientific understanding on the subject, however, suggests that current re-absorption rates, measured in relation to incremental emissions, are low, of the order of 1% pa, but may turn out to be much lower.

[15] Nature. 20 November 2008. http://www.nature.com/climate/2008/0812/full/climate.2008.122.html

[16] Jones, C.D., P.M. Cox and C. Huntingford (2006): *'Impact of climate-carbon feedbacks on emissions scenarios to achieve stabilisation'*, in Avoiding Dangerous Climate Change, Schellnhuber et al. (eds.), Cambridge: Cambridge University Press.

2. Comparing the damage between earlier and later emissions

The observation that emission of (cumulative) CO_2 this year should carry a higher SCC, and by implication a higher cost penalty, than the same quantity emitted next year, may be intuitively obvious. The algebra below is intended merely to confirm this intuition.

Let D_n be the economic damage over all future years attributed to an incremental unit that exists in the atmosphere in year n only, discounted back to year 0. Let Z_n be total impact over all years, ie an infinite series, of a one-off **emission** in year n of volume K, discounted back to year 0. [NB In this formulation impacts are always discounted back to the base year.]

Let the reduction factor V, assumed for simplicity to be constant, be the proportion of incremental CO2 ***not*** re-absorbed after a year, so that the proportion remaining after n years is V^n. [note that V =1 if there is no re-absorption.]

Now let us compare Z_0 and Z_1 as the total effects of the same emission K, but a year apart.

$$Z_0 = K \times D_0 + V \times K \times D_1 + V^2 \times K \times D_2 + \ldots + V^n \times K \times D_n + \ldots$$

$$Z_1 = K \times D_1 + V \times K \times D_2 \ \ldots . + V^{n-1} \times K \times D_n + \ldots\ldots$$

$$\text{So } Z_0 = K \times D_0 + V \times [K \times D_1 + V \times K \times D_2 \ldots . + V^{n-1} \times K \times D_n + \ldots\ldots]$$

$$= [K \times D_0] + [V \times Z_1]$$

Hence unless D_0 is zero or negative, the impact of emission in year 0 must be greater than the impact of emission in year 1 times the reduction factor; ie if the reduction is 1% pa, then SCC cannot increase by more than 1% pa.

If V=1, and the CO_2 is purely cumulative, then Z_0 is always greater than Z_1.