RISING CARBON FLUX PRICE AND THE PARADOXES OF FOREST-BASED REDUCTION OF ATMOSPHERIC CARBON STOCK

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Abstract

Reasons can be given, on both supply and demand grounds, why the price of a carbon flux into or out of the atmosphere might rise through time: such predictions are now embedded in the calculations mandated by some governments. A productive forestry cycle entails both early sequestration (at low prices) and late volatilisation (at high prices) of carbon. Hence a productive cycle might be deemed "loss-making" on its carbon account, even if in every future time period its effect on atmospheric carbon stock appeared to be not-detrimental. However, costing carbon via its lagged long-term effects on global conditions shows that a production cycle which is overall carbon-neutral can indeed have detrimental effects. While these effects might be mitigated or reversed by discounting of carbon flux values, in practice there is debate about whether such values *should* be discounted at all. The real cause of the paradox is the customary time perspective of economists, and the attendant belief about what constitutes "the end of a cycle".

Introduction

When in the early 1990s we first developed a carbon economics component for UK forest stands, we were told firmly by the then-existing Ministry of Agriculture, Fisheries and Food that "carbon-fixing effects are not significant [in farm woodlands]" (MAFF, 1994, pers. comm.). All that has now changed. Everyone is at it, making and publishing carbon models, and advising governments about the implications. The problem is, that many of them are doing it wrongly, and the governments that they advise seem unable or unwilling to discriminate: so long as they "do something about carbon", political aspirations are satisfied. Reports (e.g. Read, 2009) are sent out for review, comments – sometimes damning ones – are submitted, then commentators are told that "it is too late to change the report". They are left with no inkling of whether their criticisms have been answered, noted, or just ignored. Governments commission reports, instructing their consultants on the methods to be used and the assumptions to be made. The reports are duly compiled, submitted and published in academic journals, and the governments refer to the embodied methods and assumptions, as though these furnished independent support of their own preferences. Those who hold radically different views neither get the consultancies, nor have a channel of official criticism.

The UK's government, many other governments, and every forestry organisation or discussion forum that I know are convinced that forestry can play a role, ranging from trivial to crucial, according to the source of prices consulted, and according to the discount rate. There may be doubts about whether climate change is happening; there may be doubts about whether climate change matters; there may be doubts about whether anthropogenic CO_2 is the major cause. But everyone whose opinion counts seems to be certain that, if all the above are so, then forestry activity can have a beneficial effect. And it would, I think, be widely considered that a rising price for carbon sequestration would universally improve the case for expanding the forest area.

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This paper offers a critique of one of the consequences of what appears now to be embedded thinking on the way carbon values are derived and are permitted to influence evaluation of forestry. After outlining the history of carbon pricing, it shows how the profile of carbon prices through time may lead to an afforestation investment's having an apparently negative carbon account, even when seeming to have a demonstrably beneficial effect. It explores some possible means of reversing this unpalatable conclusion.

Carbon pricing and forestry

When carbon economics first came into focus in the early 1990s, as many as eight general methods of pricing a tonne of carbon (in the form of CO_2) were discussed. Since that time the actual figures have changed, and methods have been refined, but no new substantially different method seems to have been devised.

Table 1: Methods of pricing carbon

Flux pricing method			Time-scale	Cost/tonne
1	Growth constraint:	bottom-up	phased	£0–240
2		top-down	phased	£4–28
3	Extra cost of low carbon fuel		instant	£125
4	Ditto, discounted		future	£24
5	Cost of sequestering carbon		prolonged?	£5
6	Cost of altering radiative balance		prolonged?	trivial?
7	Lost production, damage cost and defensive spending		perpetual	20p–£90
8	Carbon tax to achieve target		undefined	£65–180

Sources: Cline (1992); Price and Willis (1993)

From the same time, forest scientists developed models of carbon sequestration during stand growth (Dewar and Cannell, 1992) and of volatilisation of carbon from products (Thompson and Matthews, 1989). The sawtooth profile for a sequence of planted and clear felled crops became familiar (figure 1).

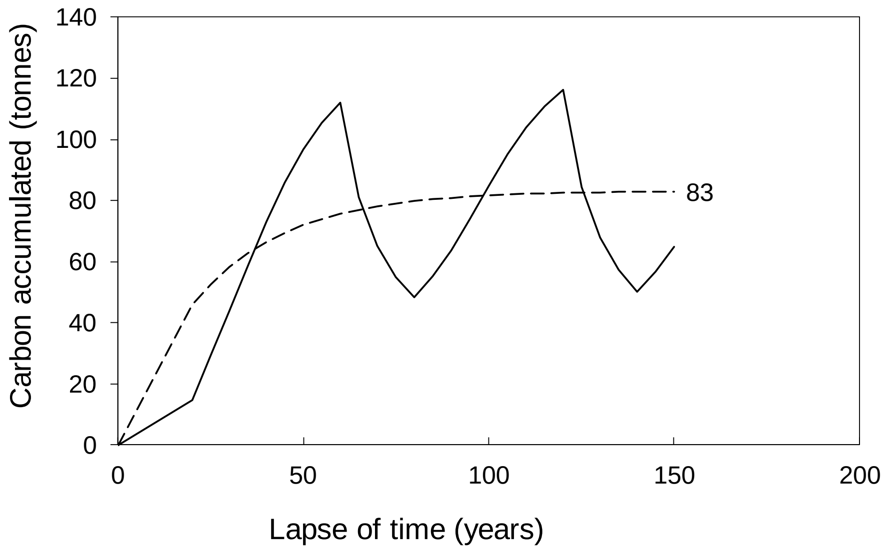

Figure 1: Net carbon accumulation from a succession of planted crops: Sitka spruce, yield class 12, thinned

Early economic cost–benefit analyses (Price and Willis, 1993) included an exogenous carbon price, applied to these profiles of carbon flux, and found that carbon price could be crucial to profitability. Later analyses turned to cost-effectiveness approaches that identified low-cost forestry options for carbon sequestration (Hoen and Solberg, 1994; Healey et al., 2000). These allowed calculation of the carbon price needed for inherently unprofitable forestry activities to break even. The latter approach developed within a wider context, of calculating intersectoral marginal abatement costs (of CO_2 in the atmosphere) for the UK (Valatin, 2010; Department of Energy and Climate Change, 2009; Read, 2009).

For various reasons to be visited later, projections are being widely made of a carbon price which increases through time. This price rise has a crucial bearing on whether and to what extent forestry investments are an effective means of mitigating the economic effects of climate change.

Rising price and stylised fluxes

To clarify the processes under discussion, take first a highly stylised plantation project, whose trees sequester *C* tonnes of carbon each year for 50 years. At the end of this time the trees are felled, and are put to uses such that, by decay and combustion, *C* tonnes are volatilised each year for a further 50 years, at the end of which time, therefore, all carbon sequestered has returned to the atmosphere.

Suppose for the sake of illustration that the initial price *P* per tonne of carbon fluxes is rising at 1% per year in real terms. Now, for every year in which there is sequestration of *C*, there is another year, 50 years later, in which there is volatilisation of the same amount, at a price greater by a factor of

$$e^{0.01\times 50} = 1.65$$

Without discounting (another matter to which we shall later return), the cash value of sequestration is

$$C \times P \times \frac{1-e^{-0.01\times 50}}{0.01} \times e^{0.01\times 50} = 65CP$$

whereas the cash cost of volatilisation is 1.65 times greater, or 107*CP* – a net loss of 42*CP*.

That a loss should thus have been made on the carbon account *ought* to come as no surprise, since for every benefit there is a greater corresponding cost, 50 years later. Indeed, with rising carbon price, for any forestry project at whose conclusion all sequestered carbon is *eventually* returned to the atmosphere, this loss is inevitable. And yet the result *feels* surprising.

Rising price and realistic fluxes

Take now a more realistic profile of carbon fluxes, those of a plantation of Sitka spruce, yield class 12 m^3 per hectare per year, thinned and grown on a *single* rotation of 60 years – about the rotation of maximum biomass productivity. Figures are based on Edwards and Christie (1981) and Thompson and Matthews (1989). As can be seen, by the end of 150 years virtually all the carbon sequestered has returned to the atmosphere.

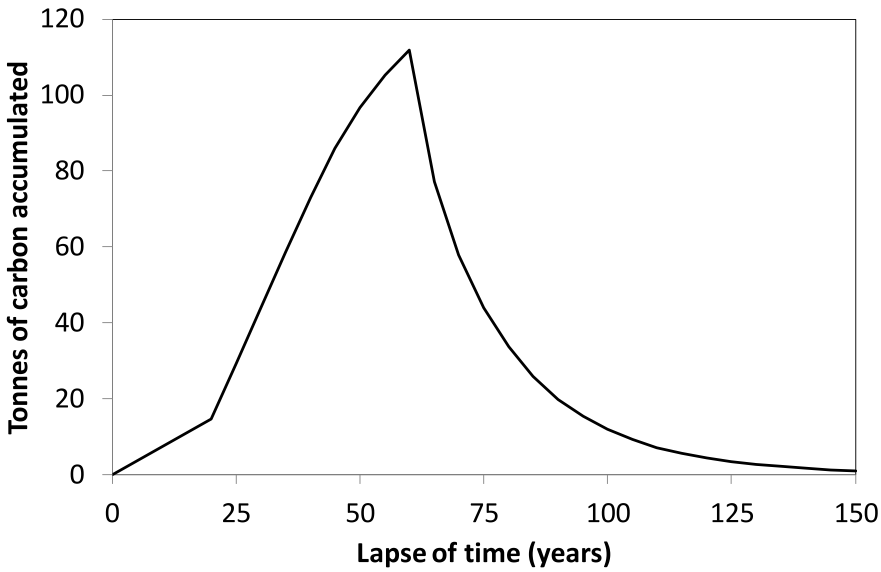

Figure 2: Storage of carbon resulting from one cycle of plantation activity

According to a conventional discounted cash flow evaluation, with a CO_2 price of £80 per tonne of carbon, no price increase, and a 3% discount rate, the carbon account for this project shows a result of familiar magnitude: a surplus of £2830. Yet with a price increase of 1% per year and no discounting, there is a deficit of £676: this despite its *appearing* that at every time, from the inception of the project to its end, at least some CO_2 will have been removed from the atmosphere, so that climate change effects should have been mitigated to some extent in all time periods. Engaging in sustained plantation forestry, such that felling is followed by regeneration, does not solve this unexpected problem, but merely replicates it, each successive rotation adding (an ever-increasing) deficit to the total carbon account.

Is this, then, just an accounting artefact? In a way it seems so. Effectively the project has sold carbon credits cheaply during forest growth, and bought them back more expensively during product volatilisation. The global profile of carbon mitigation assets held at the end of the project remains unchanged by the fact that the project was implemented: but the cheap assets available at the beginning of the forestry period have reduced the cost to everyone of purchasing offsets: everyone, that is, except the foresters, who are left with paying for the most expensive mitigation options at the rotation's end.

(In practice it might be somewhat different from this. The availability of cheap offsets from forestry might encourage greater emissions, but the later entry of foresters as purchasers of more expensive offsets would increase competition and raise prices further, thus reducing emissions. The effect resembles the expected adjustment of markets for non-renewable resources of decreasing quality (Price, 1984).

Carbon price based on the costs of climate change

At the end of the twentieth century, most discussion on carbon pricing had revolved around the costs imposed by emissions of CO_2, and their effects on the world economy, via global warming and consequent sea level rise, and through changed rainfall regimes. The kinds of costs discussed included:

- opportunity costs, such as from agricultural production, lost on inundated coastal land or reduced on droughted land;
- damage costs, like those arising from increased storminess;
- health costs through heat stress or migration of disease zones;
- defensive costs, such as construction of sea walls;
- mitigation costs, for example more temperature amelioration expenditure;
- retreat costs, such as rebuilding cities in less vulnerable locations.

Importantly, some of these costs might be expected to grow more-or-less in line with the world economy: for example, with improved food productivity, agricultural opportunity costs rise; with more structures to damage or to be relocated, rising sea level and greater storminess inflict more damage; with greater population and higher unit labour output, days lost through health problems have greater impact on the monetised economy. Unlike the redistribution of the cost of owning abatement assets, these are real costs to the global economy, that really might become more serious as time went on.

Even so, it seems that a forest rotation such as that shown in figure 2, which always has a non-negative stock of sequestered carbon, should not be capable of inflicting overall cost. That its effect is not so benign is a consequence of lags in the physical system which mediates climate change.

Firstly, excess CO_2 in the atmosphere is uptaken into the oceans, according to processes that are complex but relatively well-quantified. There is also *additional* uptake into terrestrial ecosystems, especially boreal forests (Lindner and Karjalainen, 2007), which is less well quantified, and will not be included in the models given below.

Secondly, owing to the thermal inertia of the oceans, there is a lag in the warming process, the temperature adjusting about 5% per year towards what the equilibrium would be *at that level of* CO_2. But emissions and uptake of CO_2 continue, and equilibrium is never established. There are also processes on a time scale of millennia which lead to warming of the deep oceans (Wigley, 1993), but these are not considered.

In these global processes, one hectare of forest plays a minute part, that could never be detected instrumentally within the vast secular changes: what follows represents effectively the partial differentials of change that might be attributable to the forest.

The best-known *economic* expositions of the oceanic processes are those of Nordhaus (1991, 1992, 1993). These disastrously over-simplify the complex process of oceanic uptake, appearing to entail *instant and complete disappearance* of 36% of material emissions, while the remainder are uptaken by the ocean such that the atmospheric residue declines asymptotically to zero. The reasons for these mistaken results, which contradict both first and second laws of thermodynamics, are discussed further in Price (1995). Nonetheless, Nordhaus's model will be used in sensitivity analysis.

A more accurate (though still thermodynamically incoherent) model of uptake has been published by Siegenthaler and Sarmiento (1993), and this will provide the base model which follows.

A linear relationship is assumed between atmospheric CO_2 concentration and temperature, and between temperature and damage. (Once more complex relationships are introduced, it is impossible to model the effects of forestry independently of a complete system model.) Unless the overall relationship between damage and atmospheric CO_2 were to rise to an asymptote within the time-frame of analysis, it is believed that the results recorded below would be stable in their general disposition.

All the elements required to construct an integrated model are now in place, and the results for our exemplar forest stand are illustrated in figure 3a. The accumulation and subsequent volatilisation of forest carbon has already been discussed. Forest accumulation is achieved by a deficit of atmospheric CO_2, but this deficit is mitigated through time by oceanic uptake: just as emissions accelerate oceanic uptake, so sequestration reduces it. By the end of one rotation, more than a third of the forest's uptake has been offset by reduced oceanic uptake. Following felling, initial volatilisation of forest products is rapid, adding more CO_2 to the atmosphere than is offset by accelerated oceanic uptake. After about 80 years the project has led overall to a higher CO_2 concentration in the atmosphere. After 110 years, the cumulative effect of the time-profile of atmospheric CO_2 is that temperature is higher than it would otherwise have been. At this point, the profile of cumulative damage mitigation turns downwards. The net cumulative damage mitigation has not reached zero by 200 years, but seems set to do so within a few decades.

With a carbon price increase of 2% per year, cumulative damage mitigation has changed to cumulative damage aggravation by 180 years (figure 3b).

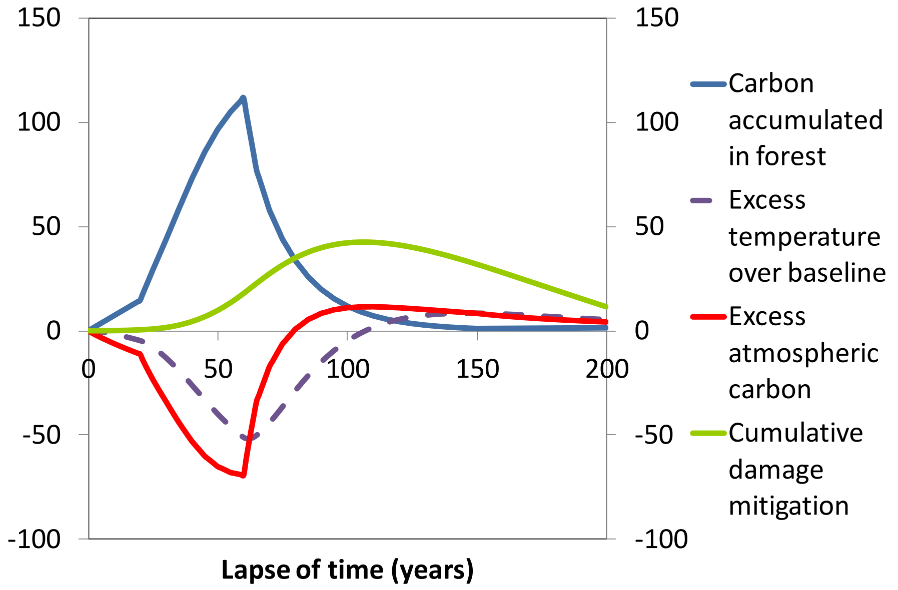

Figure 3a: Effects consequent on a forest rotation, 1% per year carbon price rise
Carbon figures are in tonnes; temperature and damage are on arbitrary scales.

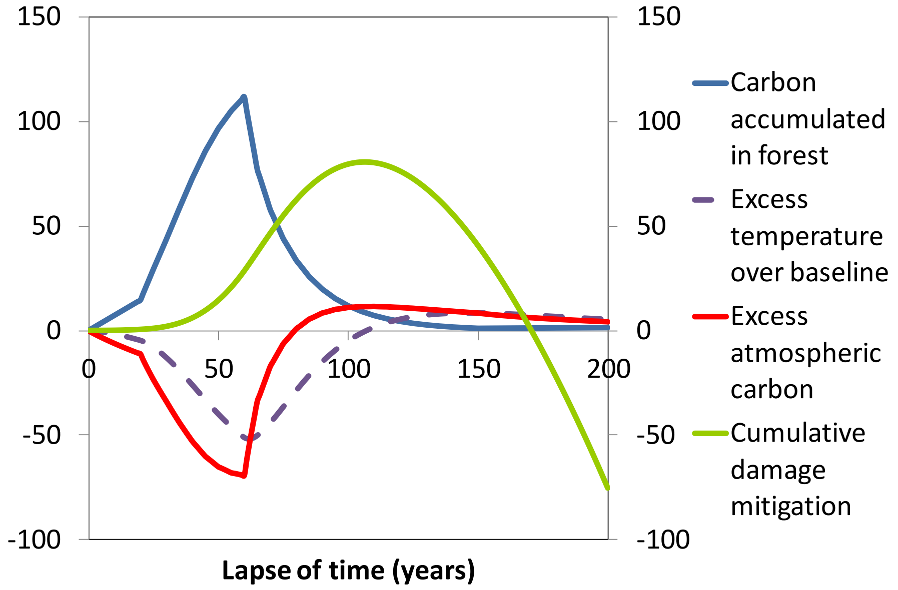

Figure 3b: The same, but with a 2% price rise per year

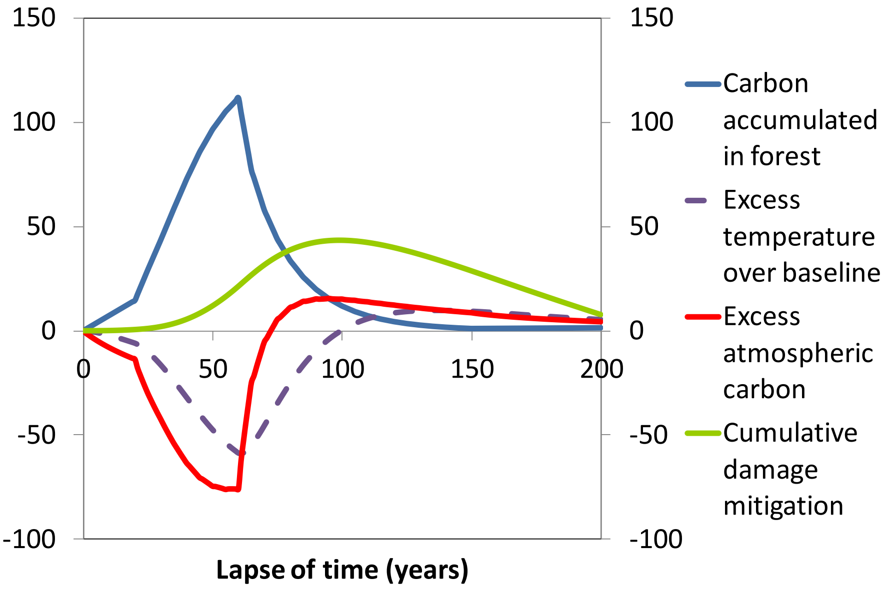

Figure 3c: 1% price rise, Nordhaus's assumptions (36% instant uptake, 64% of uptake at 0.83% per year)

New section: mitigation cost with rising trajectory

Possible ways of alleviating the paradoxes

If the argument and figures presented above are valid, then foresters and environmental economists need to rethink. The sensitivity analyses so far performed suggest that the paradoxical results are robust to reasonable changes in assumptions. But are there modes of analysis which show the paradoxes in different light? Are there forestry options which demonstrably mitigate the calculated cumulative damage, or have a positive carbon account, or (preferably) both?

Consider first lengthening the forest rotation, so that carbon is locked up for longer. Perhaps by now the result, as shown in figure 4, should be predictable: the longer the time of volatilisation is delayed, the higher the prices at which it is costed, and the *more negative* the carbon account; furthermore, the longer the rotation, the greater the number of units to which a negative value is attached.

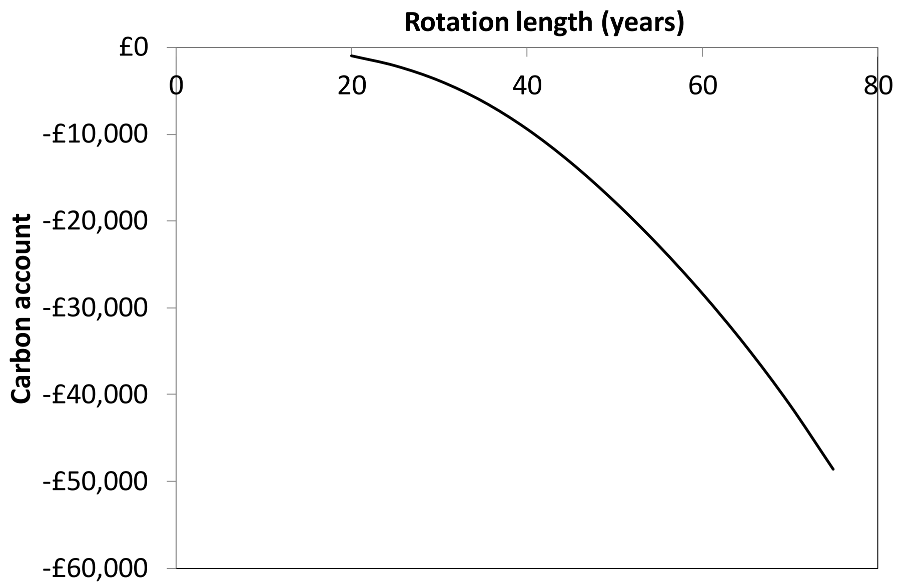

Figure 4: Rotation and the carbon account. Carbon price rising at 2% per year

Next, consider the question of forest products which displace high-embodied-carbon materials such as steel. These are seen as one of the most effective ways of deploying forestry for carbon abatement (Price and Willis, 2011). Yet they avoid carbon emissions immediately after felling, when carbon price is still low, whereas the emissions due to decay of the products are spread over a long future, when carbon price is progressively higher. Only in combination with very rapid decay rates of all products (whose adverse costs therefore also come early) does product displacement result in a positive carbon account, and it is hard to imagine the usefulness of a product which displaces, say, structural materials, but itself needs replacing very frequently!

As it happens, under the UK's present accounting rules for carbon, product displacement is excluded as an allowable benefit (Read, 2009).

On the other hand, the displacement effects of biomass burning *are* allowable by the UK government. Entailing as they do instant volatilisation (that is, combustion), the carbon costs are immediately – and therefore cheaply – disposed of: all, that is, but those very considerable and long-delayed ones caused by the slow decomposition of non-timber forest biomass, something which has heretofore been considered a *valuable* feature of forestry's carbon interactions. Not so: the greater the non-timber biomass, the more negative the carbon account becomes.

But any option, such as fertilising or enriching a degraded forest with the intention of building up the growing stock without any later exploitation, would show a positive carbon account, according with the argument below concerning establishment of a normal forest.

Given the apparently relentless perversity of results so far, there should be no surprise at the result of a project which entails deforestation, followed by replanting of the cleared ground, ending when the carbon stock is fully restored. This would be appraised as being better than the do-nothing project of retaining the forest area, because early deforestation enhances oceanic uptake, so that the regenerating forest eventually brings about lower atmospheric CO_2, as figure 5 shows. Eventually, the consequent temperature is lower than it would otherwise have been, and the cumulative damage function turns downwards.

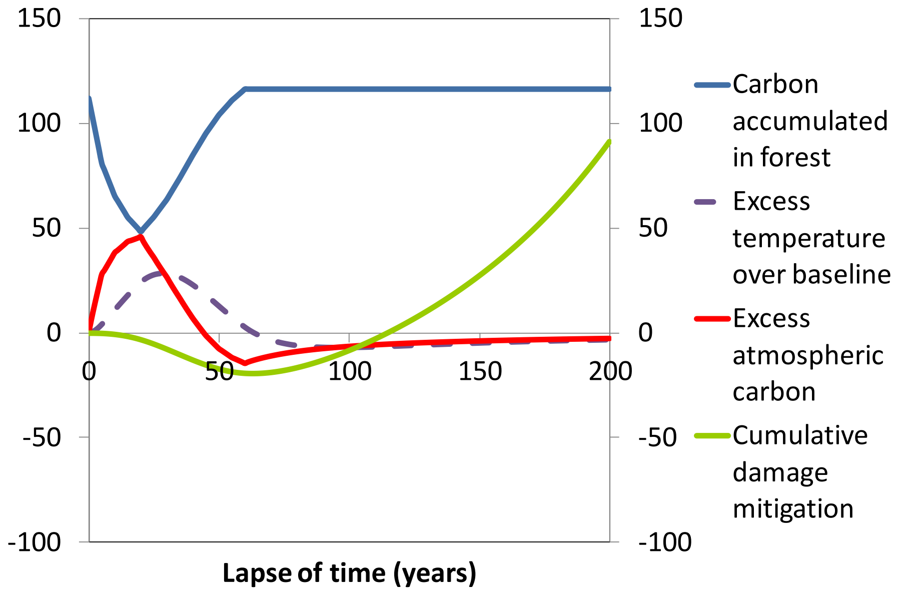

Figure 5: The consequences of an exploitation project

Of course, it *really ought to* make sense to ship CO_2 into the atmosphere as soon as possible and thus accelerate oceanic CO_2 uptake, while damage cost is still low. According to this thinking, the projects that most deserve praise (deforestation and degradation) are the very ones which usually attract the most fervent criticism, as "short-termist" and "exploitative"; outlay on regeneration is seen as conscience money expended, too little and too late. From the viewpoint considered here, the later the better! Slow regrowth is more advantageous than rapid regrowth, and "enrichment planting" to accelerate re-establishment of forest cover is actually detrimental to the carbon account.

It could be said, however, that delayed deforestation and regrowth is even more beneficial than doing it immediately.

The normal forest option

Figure 6 shows the carbon storage by developing a 60-hectare normal forest of thinned Sitka spruce yield class 12 on a 60-year rotation. Each year another hectare is planted, so that all ages classes are present by the time of the first clear felling. The dashed line shows the stock on one hectare of land. The solid line, representing all 60 hectares, shows that the forest/forest products system always gains carbon, even after volatilisation of products begins. As an all-aged forest is achieved, the net carbon storage tends to stabilise, because at all times the same age-class and volume-class and carbon-mass-class structure is in place. The remaining slight accrual is attributable to the accumulation of slow-decaying products. Since there is never net loss into the atmosphere, the creation and continued management of the forest can never lead to higher atmospheric CO_2, nor to any consequent temperature rise above base-level, nor to any ensuing net damage. According to the Siegenthaler and Sarmiento (1993) model of oceanic uptake, 13% of carbon in the forest stock will be permanently removed from the atmosphere, and since there is never any surplus of volatilisation over growth, the amelioration of climate change costs will be permanently achieved in each time period. This is so, whatever the path of price change (except in the case that stored carbon comes to have a negative price, in which case the entire forest can be immediately felled and burned).

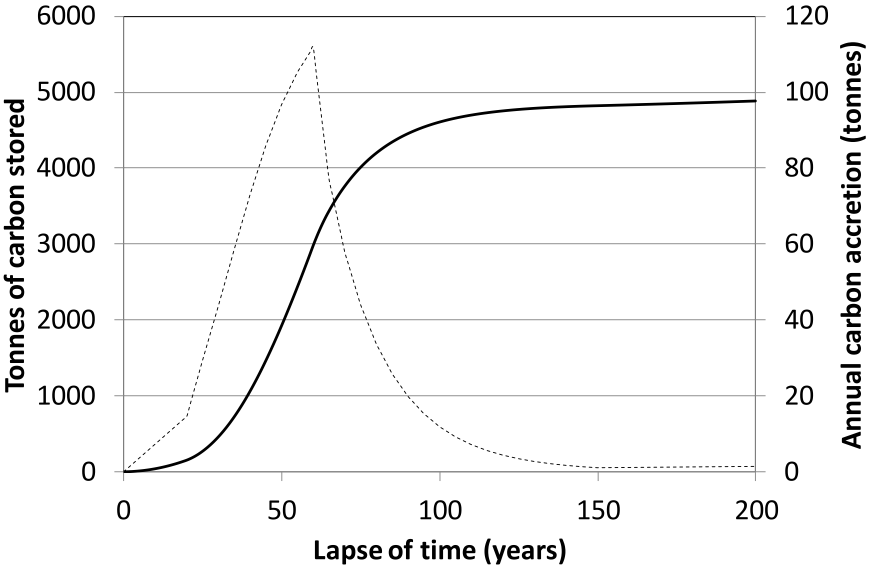

Figure 6: Carbon storage by developing a 60-hectare normal forest

And yet if each stand were to be treated by itself, under rising prices each would show a negative carbon account. How can it be that a summation, each of whose elements is negative, can become positive for the whole forest?

The strange-seemingness of the answer is due to the customary perspective of economists on the future. Forest economists in particular are accustomed to "taking everything into account" by summing the NPVs of a perpetual series of rotations. It does not matter what happens "at the end of time" – or where, precisely, we place the end of time in the rotational cycle – because discounting reduces all that happens in so distant a future to nugatory value.

By contrast, with no discounting and a rising carbon price, what happens at our distant-future time horizon, and where we place that horizon in relation to the rotational cycle, may have dominating significance. By taking a completed single rotational cycle as our unit of valuation, we suppose that "the last things" are the completion of volatilisation. We cannot legitimately sum these to constitute the case of a formed normal forest, because for that forest "the last things" are the settlement into a permanent state of positive carbon storage. This would be truly sustainable forest management.

With single-aged forests, too, an escape from the paradox can now be seen. Our analysis has thus far considered a cycle ending with completed volatilisation. This is an arbitrary position in the cycle. If we take all points in the cycle to be equally likely as "the last things" state, we gain the same result as is shown by the normal forest, the "normality" now being in the rectangular probability distribution of age classes. The same issue, and the same resolution, are seen in the determining the optimal rotation with a negative discount rate (Price, 2012).

The same radical perspective may be applied to the deforest–regrow project. The "last things" could as likely be the deforestation event as the completion of the growth cycle. Seeing things this way, deforestation leads to a mean decline in the most valued carbon stock.

The only paradox, actually, might be the one that is created through taking an inappropriate perspective.

Discounting our way: out of or into trouble?

With conventional discounting, the paradoxes reviewed above do not arise. Provided that the discount rate is higher than the rate of carbon price rise, the volatilisation phase of the forestry cycle, coming late in time, brings carbon account costs that are discounted to lesser significance than the benefits of the early growth phase.

If discounting "solves" the paradox, and if discounting constitutes the present norm, why has it been omitted in all the analysis so far? There are three answers.

- Discounting is prone to obscure whatever it is that happens in the long term. There is reason to inspect the results arising when discounting is not practised, to understand potential outcomes that would otherwise be hidden, in case there should be matters of importance embedded therein.
- Not discounting at all demonstrates the limiting case of discount rates being lowered, especially for the long term, as has been proposed officially (UK Treasury, undated; Lebègue et al, 2005). In fact the results shown above would be reproduced if the rate of carbon price rise ever came to exceed the discount rate.
- There is an argument against discounting anyway (Price, 1993), particularly in relation to effects which are not susceptible to the main ethical case for discounting – that it allows for diminishing marginal utility of increased per capita consumption (Price, 2003).

Technological advance in carbon storage might indeed reduce the significance of carbon sequestration in forests, but perhaps that might be treated as one possible scenario for carbon price, rather than being wrapped up in a discount rate. Moreover, a world of much greater affluence might better be able to bear the expenditures and opportunity costs of *not* abating climate change, or of not volatilising carbon. If so, that too should be the subject of explicit prediction. Hiding the future, by the general application of a standard discount rate, is not a responsible attitude to such problems.

Howsoever any of *that* might be, not-discounting carbon values is not a novel suggestion. Among those who have followed such a protocol are Sedjo and Ley (1997) and Moran et al. (2008). I do not think that these authors were aware of the full implications.

Sensitivity analysis demonstrates what might be expected: that the discount rate strongly affects the outcome of analysis concerning forestry projects. What might not have been expected is the direction of its influence: that carbon sequestration by new forests is most valuable at moderate discount rates, and becomes a liability as the rate falls below 2% – the rate here adopted as the rate of carbon price rise. (The break-even point is slightly above 2%, because a small carbon cost for harvesting machinery is included.)

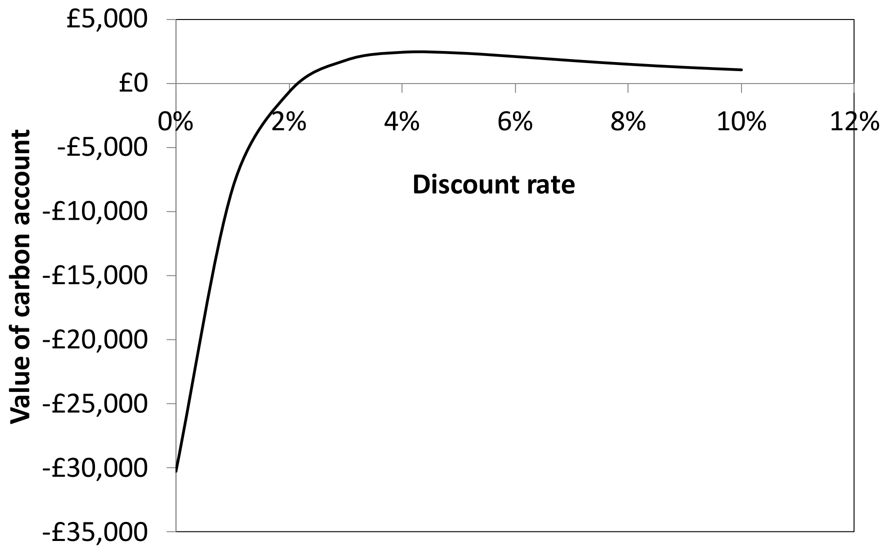

Figure 7: Carbon account value at various discount rates; 2% carbon price rise, includes effects of fossil fuel in harvesting

This is another paradox, because it would be firmly believed that a lower discount rate for carbon favours forestry carbon sequestration (Price, 1990), whereas it actually makes it more likely that carbon sequestration projects will have a negative value. That is the case, at least, until we reorientate our time perspective.

It is discounting that has to date covered over the "problem" of late carbon costs, merely *obscuring* the paradox, not resolving it at all: low discount rate makes timber benefit appear very important: thus any carbon account loss is invisible until sufficiently rising prices thrust forward its importance.

Paradoxes: real or illusory?

The *real* problem is, that just doing carbon accounts as *fluxes* priced according to a lump sum value does not recognise the key fact, that the important mediator of damage is the atmospheric *stock* of CO_2. Incorporating this route to pricing in cost–benefit analysis of forestry carbon projects seems to give to carbon the importance that is due, in *all* phases of the project.

With conventional discounting that exceeds the rate of carbon price rise, forestry investments will *appear* to have what is *actually* a beneficial effect.

The apparently detrimental effect when price rise exceeds discount rate is an artefact of the part of the investment cycle that is conventionally seen as "the end". In reality, cycles are things that do not end.

Foresters can, I believe, breathe a sigh of relief: forestry projects which enhance the stock of sequestered carbon *on an average taken through the project cycle* do mitigate any damage that might be attributed to climate change. But it needs mindful analysis in order to demonstrate this.

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