The ‘Hidden’ Social Costs of Forestry Offsets

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Published in: *Mitigation and Adaptation Strategies for Global Change*, 14(2):107-120.
Published at: http://www.springerlink.com/content/e6287v1727526317
DOI: 10.1007/s11027-008-9153-6
This version: 26 January 2009

ABSTRACT

The article quantifies the size of ‘hidden’ social costs that are incurred by forestry offsets in the voluntary market that promise to offset present emissions sometime in the future. It does this by estimating the difference between the social costs of carbon emitted and of costs offset by removal of carbon (C) from the atmosphere by reforestation/afforestation. All current attempts to make forestry offsets more reliable focus on quality control rather than the mismatch of the timing of emissions and their offset. Recommendations that follow from the analysis are twofold. First, that markets for carbon dioxide equivalent (CO_2e) removals by voluntary offsets should be confined to the annual incremental removals actually achieved. Second, the promoters of voluntary offsets projects should declare the annual stream of carbon credits and debits expected so that buyers can place a present value on such projects.

1. INTRODUCTION

It is suggested that forests can make a very important contribution to a global climate mitigation portfolio that provides synergies with adaption and sustainable development but only a small proportion of this potential is being realized at present (Nabuurs *et a*l 2007; Capoor and Ambrosi 2007)). Forestry includes the maintenance of existing forests and the increase of forest area. The United Nations Framework Convention on Climate Change (UNFCCC) definition of “reforestation” is adopted for the analysis, but it also holds for “afforestation”, achieved where trees replace other permanent landuses (UNEP Riso 2008). The gain is the difference between carbon (C) bio-sequestered with the forestry project and without the project. However, markets are in terms of tonnes of carbon dioxide equivalent (CO_2e), rather in C, where 1 tonne of C = 3.67 tonnes of CO_2, and where CO_2e is the expression of the global warming potential of greenhouse gases (GHGs) in terms of their equivalence with CO_2 (IPCC 2007, Table 2.14, p. 212).

Regulatory schemes that allow credits to be generated by forestry offsets are the Greenhouse Gas Reduction Scheme of New South Wales, Australia, that caps emissions associated with the production and use of electricity (Greenhouse Gas Reduction Scheme 2007) and, in the U.S., the Regional Greenhouse Gas Initiative of 8 eastern U.S. states, which will cap emissions after 2009 and will include forestry (Regional Greenhouse Gas Initiative 2007). California will cap emissions after 2009 and already has a Climate Change Registry that includes forestry protocols (California Environmental Protection Agency 2007).

The largest regulatory cap and trade scheme by far is the EU Emission Trading Scheme (EU ETS) launched in 2005. While EU member countries can trade allowances with one another, and they may buy and sell Certified Emission Reductions generated under Joint Implementation or Clean Development Mechanism (CDM) projects of the Kyoto Protocol, forestry credits cannot be generated within the EU ETS (Europa 2008).

The Chicago Climate Exchange (CCX), with subsidiaries in Europe, Montreal, and the North East States and New York, facilitates trade between members who have voluntarily signed up to its mandatory reductions policy of reducing CO_2e emissions by 6% below the 1998-2001 baseline by 2010. Trades are mainly between members whose emissions are either below or above their targets, but forestry offsets are also an option (Chicago Climate Exchange 2008).

Unlike the regulated markets – where emitters have a monetary incentive to offset rather than abate emissions – the voluntary market does not rely on legally mandated reductions to generate demand. Instead, the demand is driven by public image considerations and a sense of moral obligation. Offsets are sold on the basis that a sufficient area will be afforested to sequester a mass of carbon equivalent to 1 tonne of CO_2e emitted in the present, by some future year (often in a 100 years' time). In contrast to practise in regulated markets, voluntary deals are often negotiated on a case-by-case basis requiring no certification or verification, nor registration with a central authority that maintains a greenhouse gas inventory. While the voluntary market is small, it is growing quickly; one estimate put the 2007 market volume traded at approximately 100Mt of CO_2e (Bayon, Hawn and Hamilton 2007, Table 1.1, p.14).

Advantages of the voluntary market are that (1) there is a wide range of offset products available; (2) transaction costs are low relative to creating CERs (carbon credits approved by the CDM Executive Board) and (3) it provides individuals as well as institutions and corporations with the opportunity to play a role in mitigating global warming, often as part of a "carbon neutral" strategy, i.e. a strategy that abates or offsets all of an entity's carbon emissions. Brokers and wholesalers link the demand for forestry offsets with a supply of bio-sequestered carbon via retailers. The voluntary markets deal in Voluntary Emission Reductions (VERs) which are verified either by the project managers themselves or by third parties. VERS, certified or not, are not tradable in the official exchanges set up under the Kyoto Protocol or by governments, such as the Automated Power Exchange in California (Energy-Exchange 2008) and the Greenhouse Friendly scheme in Australia (Australian Government 2006a).

Forestry is the most popular offset mechanism in the voluntary market. Customers see trees and forests as tangible, providing habitat and generating community benefits (Brand and Meizlish 2007). Of the 43 retailers of offsets listed by Bayon, Hawn and Hamilton (2007, p.126), 23 sell forestry offsets: some exclusively and some with a mix of products.

2. CRITICISMS OF VOLUNTARY OFFSETS

Because forest offsets take time to remove carbon from the atmosphere, they are not perfect substitutes for immediate abatement of emissions. Until full offsetting occurs at the end of the period over which the offset is planned, a stock of GHGs remains in the atmosphere, causing climate change and thus causing damage costs to society. Energy efficiency measures, for example, deliver abatements more quickly than afforestation or reforestation, while avoidance of fossil fuel use delivers abatement immediately.

This problem is taken up by commentators criticizing forestry offsets in contemporary markets on the grounds that carbon savings accruing for periods of 70 to 100 years (Bayon, Hawn and Hamilton 2007, p. 113) are being counted by sellers of offsets as savings made in the present, with *ex ante* payments being made on this basis (see for example Smith et al. 2000; Neef et al. 2007; Smith 2007).

Despite a serious lack of transparency in voluntary markets, all current attempts to make offsets more reliable, including ISO standards and the Voluntary Carbon Standard, focus on environmental standards and quality control in measurement and additionality of carbon and not on the mismatch of the timing of emissions and their offset (BusinessAssurance 2007).

The issue of the temporal value of carbon that has been removed from the atmosphere and stored, as compared to carbon stored as a result of activities taken to avoid emissions, was addressed by Moura-Costa and Wilson (1999) and Fearnside et al. (2000). In their approach of “ton years”, credits are awarded for the number of tonnes held out of the atmosphere for a given number of years and some equivalence factor would be defined to equate a specific number of ton years with permanent sequestration enabling a ‘pay as you go’ basis. However, there is a lack of symmetry between the credits and debits, which we show is important in avoiding social costs. Moreover, the ton year concept accumulates credits very slowly, rendering it unattractive financially (Cacho et al. 2003).

This article quantifies the costs to society of the time lag between immediate emissions and the eventual carbon sequestration by forests. First, we estimate the social cost of the time lag by adapting the well-known DICE model (Nordhaus 1994). Because the cost estimates produced by this model are highly sensitive to the discount rate, we present estimates using a range of discount rates. Second, we explore the implications of these cost estimates for forestry offsets markets. In particular, we estimate the additional amount of forestry needed to achieve “cost neutrality” instead of just carbon neutrality.

3. TIME LAG COST ESTIMATES

3.1 Marginal social cost of carbon

Markets for carbon credits and offsets deal in metric tonnes of CO_2e. The methodology in this section of the paper, however, is in terms of tonnes of elemental carbon.

Estimates of the marginal social costs (MSCs) of carbon released to the atmosphere vary widely (Yohe at al. 2007). The range mainly reflects divergent views on how future costs should be valued in the present but also reflect what is being measured. Published estimates of MSC of carbon are invariably in the form of a single present cost at a certain discount rate. Moreover, they may be estimates of the present value of MSC of a tonne of carbon emitted in each year in the future, rather than estimates of the MSC of a single pulse of one tonne emitted at the present. In this paper the MSC of carbon is the annual cost, reflecting its decay over time, of a pulse of 1t of C emitted in year 1.

We simulate a profile of MSCs of one tonne of carbon emissions over 400 years, in the absence of policy intervention, using data from the DICE model from the Appendix in Nordhaus (1994). Updated data from the model, in 2000 dollars, was provided by William Pizer (Resources for the Future, Washington DC, personal communication) and is depicted in Figure 1.

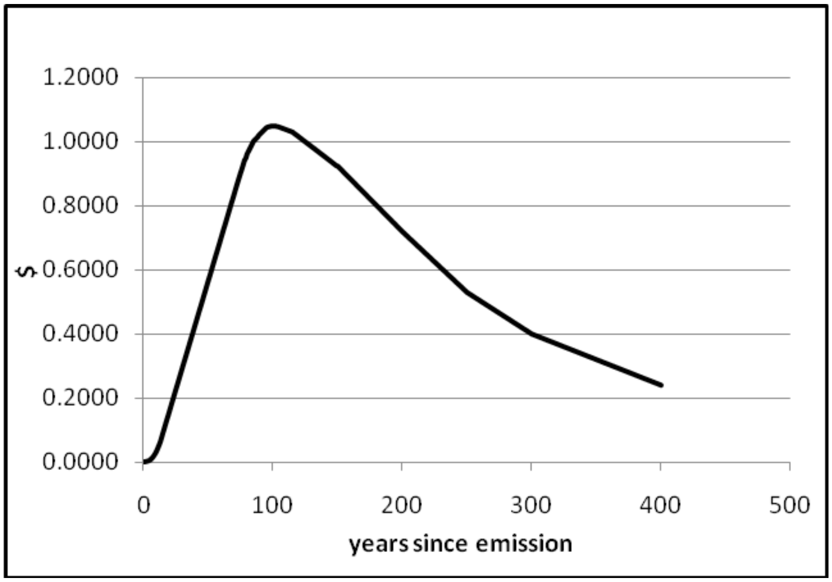

Figure 1: Marginal social cost of 1 tonne of C emissions, 400 years, 0% discount rate, year 2000 dollars. The marginal social cost is the cost in each year subsequent to the emission in year 1 of 1 tonne of C. Source: Nordhaus (1994).

3.2 Incremental sequestration of carbon

The next step is to adopt a profile over time of the total mass of carbon sequestered by afforestation/reforestation and from that the total incremental mass of C sequestered. The profiles of total on-site mass of C, comprised of C in debris, weeds, soil and trees sequestered over 100 years by reforestation are determined for a location in tropical Australia. See Figure 2. It is assumed that trees replace grassland on land cleared prior to 1990, thus meeting the additionality requirement for forests as carbon sinks under Article 12 of the Kyoto Protocol (UNFCC 2008b).

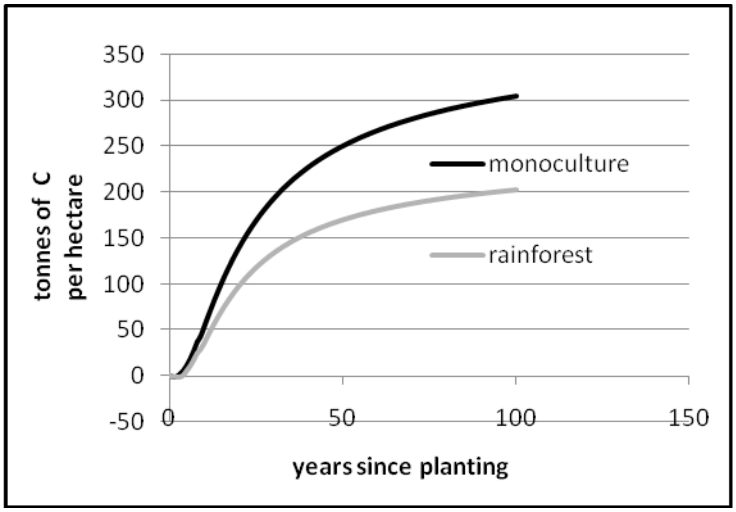

Figure 2: Total on site tonnes of C sequestered by a monoculture of hoop pine (Araucaria cunninghamii) and by mixed native rainforest species over 100 years. In the tropical north Queensland environment reforestation with mixed species rainforest trees is expected to remove 200 tonnes of carbon per hectare from the atmosphere, while a faster growing monoculture of hoop pine is expected to sequester over 300 tonnes per hectare.

The pine monoculture plantation of hoop pine (*Pinus caribaea var. hondurensis*) has a faster growth rate than the rainforest plantation comprised of mixed species native to the area in tropical Australia, as shown in Figure 2. The growth rates are derived from the carbon toolbox (Australian Government 2007) which facilitates modeling of carbon sequestration rates for forests under varied Australian conditions.

However, it is the shape of the sequestration curve that determines the effectiveness of the offset. While the growth rates of forests differ, the incremental sequestration in achieving 1t of carbon in 100 years varies little between the two types of afforestation/ reforestation compared. The profiles for the incremental and cumulative sequestration of 1 tonne of carbon are compared for the pine and native species plantations and are found to be almost identical, as in Figure 3. (The negative rates of sequestration immediately after establishment reflect diminishing carbon in grassland being replaced by trees.)

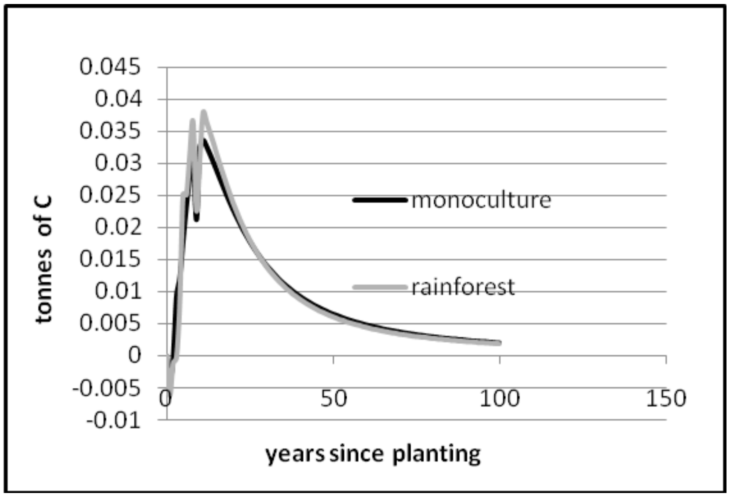

Figure 3: Incremental tonnes of C sequestered, to 1 tonne, by a monoculture of hoop pine and by mixed rainforest species over 100 years. While the rates of removal of C from the atmosphere per hectare differ between reforestation with mixed rainforest species and faster-growing monocultures, the marginal rates of sequestration to one tonne of C are almost identical.

The profiles of carbon sequestration for afforestation or reforestation in most global locations are expected to be very similar to each other, with peaks in rates at around 10 to 15 years, and most carbon sequestered by year 85. For example, see Birdsey (1996) and Stavins and Richards (2005) for profiles of carbon sequestered by timber plantations in the United States and the Australian Government's guide to forest sink planning (Australian Government 2006b, Figure 1, p. 8).

Given the close similarity between the shapes of the marginal sequestration curves to 1 tonne of C sequestered, from here on reforestation by a monoculture is synonymous with reforestation by rainforest species.

3.3 Discounting the MSC cost estimates

The discount rate will be influential in determining the present value of emissions offset and not offset by forestry over time. The next step in modeling is therefore to generate the MSC of 1 tonne of carbon offset and not offset over time at different discount rates, (all dollars are U.S.).

3.3.1 Constant and certainty equivalent discount rates

This choice of discount rate has been the subject of extensive discussion in the climate change literature (Tol 2007, Yohe et al. 2007). In deference to this ongoing debate, we present results using several approaches to discounting:

(i) A constant 4% rate based on the long term U.S. bond rate (Newell and Pizer 2000) that corresponds with the "descriptive" approach to discounting (Arrow et al. 1996).

(ii) A "certainty equivalent" discount rate that declines from 4% to 2% over 100 years. This approach takes into account our uncertainty about how interest rates will fluctuate over time (Newell and Pizer 2000).

(iii) A constant 1% rate that corresponds with the "prescriptive" approach to discounting (Arrow et al. 1996).

Equations (1) and (2) show the derivation of the present cost of emissions at constant and certainty equivalent discount rates respectively.

3.4 The present cost of 1 tonne of C emitted in year 1

The present social cost of 1 tonne of carbon emitted in year 1 at a constant discount rate is expressed as:

$$PC = \sum_{t=1}^{n} MSC_t / (1+r)^t \quad (1)$$

Where: PC = Present social cost of 1 tonne of C emitted in year 1, $

MSC = Marginal social cost of 1 tonne of C emitted in year t, $

t = year

n = year of offset project expiry

r = discount rate, which is a function of t.

The present total cost of 1 tonne of emitted at a certainty equivalent discount rate is expressed as:

$$\text{PC Cert Equiv} = \sum_{t=1}^{n} MSC_t * \check{r}_t \quad (2)$$

Where: PC Cert Equiv = Present social cost of 1 tonne of C emitted in year 1, $

MC = Marginal social cost of 1 tonne of C emitted in year t, $

t = year

n = year of offset project expiry

$\check{r}$ = certainty equivalent discount factor for period t.

Given the nature of the certainty equivalent rate, which declines continuously, it is influential in increasing the value of a tonne of carbon compared with a constant discount rate of 4%. The substitution of the certainty equivalent rate for the constant 4% rate increases by 27%, to US$7.2, the present value of a tonne of carbon emissions avoided or offset over 100 years (See Table 1). As would be expected, given the shape of the MSC curve, the present value of 1 t C emitted is very much greater at low discount rates than at the certainty equivalent and 4% rates.

Discount rate	Present social cost 100 years
0	55.9
0.01	28.9
Cert equiv	7.2
0.04	5.6

Table 1: Present social costs of 1 tonne of C emitted in year 1, at different discount rates, over 100 years, $

3.5 Achieving a physical forestry offset

Equation (3) shows the specification for a physical or 'carbon neutral' forestry offset.

A forestry offset occurs when the sum of the annual weight of carbon sequestered in the target year for offset, n, equals the mass of carbon emitted in year 1.

$$FO = \sum_{t=1}^{n} IS_t = C_1 \qquad (3)$$

Where: FO = Forestry offset carbon, tonnes in year n
IS = Incremental C sequestered, in year t, tonnes
C_1 = carbon emitted in year 1, tonnes
t = year
n = year of offset project expiry.

3.6 Costs not offset at constant and certainty equivalent discount rates

The derivation of the present cost of the emission of 1 tonne of C not avoided by a forestry offset, at constant discount rates, and at certainty equivalent discount rates are shown in (4) and (5).

$$CFO = \sum_{t=1}^{n} MSC_t (1- IS_t) / (1+r)^t \qquad (4)$$

Where: CFO = Present val. of social costs not offset, at constant discount rate, $
MSC_t = Marginal social cost 1t C emitted in year t, $
IS_t = Incremental C sequestered in year t that gives 1 t C sequestered in n years, tonnes
r = discount rate which is a function of t
t = year
n = year of offset project expiry.

$$\text{CFO Cert Eqiv} = \sum_{t=1}^{n} MSC_t (1- IS_t)^* \check{r}_t \qquad (5)$$

Where: CFO Cert Equiv = Present value of costs not avoided by physical offset, certainty equivalent discounting, $
MSC_t = Marginal cost 1t C emitted in year t, $
IS_t = Incremental C sequestered in year t that gives 1 t C sequestered in n years, tonnes
$\check{r}$ = certainty equivalent discount factor in year t
t = year
n = year of offset project expiry.

Given the urgency of reducing or offsetting emissions in the short run the models are calibrated to investigate the effectiveness of offsets designed to be carbon neutral in 30 years as well as in 100 years.

3.7 Harvesting models

Harvesting afforestation plots has the effect of reducing above ground carbon. In the model, a hoop pine monoculture is subjected to two prunings and two thinnings before harvesting followed by replanting. Under Kyoto Protocol rules it is assumed that all above ground carbon is emitted after harvest (UNFCCC 2005). We investigate the effect of harvesting on total carbon sequestered and emissions offset with harvesting and where 35% of the harvested timber is sequestered permanently in buildings (Thamer 2006). The harvest model incorporates thinning and pruning as well as harvesting; the thinnings and prunings being left on the forest floor.

The models that specify MSCs offset and not offset by hoop pine with harvest, and with allowance for the sequestration of product, are in (6) and (7) follows:

$$CFO = \sum_{t=1}^{n} MSC_t \, (1-ISH_t)/(1+r)^t \qquad (6)$$

Where CFO = Present value of social costs not offset, $

MSC_t = Marginal social cost 1t C emitted in year t, $

ISH_t = Incremental C sequestered in year t after harvest that gives 1 t C sequestered in n years, tonnes

r = discount rate

t = year

n = years of offset to project expiry.

$$CFO = \sum_{t=1}^{n} MSC_t \, (1-ISHS_t)/(1+r)^t \qquad (7)$$

Where CFO = present value of costs not offset, $

MSC_t = marginal social cost 1t C emitted in year t, $

$ISHS_t$ = Incremental C sequestered in year t after harvest and sequestration of product that gives 1 t C sequestered in n years, tonnes

r = discount rate

t = year

n = years to project expiry.

4. RESULTS

The value of the proportion of costs not offset (i.e. the difference in the integrals for sequestration and marginal cost) varies with the discount rate. The lower the rate the smaller the proportion of costs not offset, reflecting the impact of a rate on the shape of the MSC curve relative to the marginal rate of carbon sequestered. Net costs are incurred in the early years of an offset when the rate of MSC increase is greater than the marginal sequestration rate. At the certainty equivalent discount rate, 21.4% of present costs were not covered in the 100 year offset.

This effect of mismatch between the rate of increase of marginal costs and marginal carbon sequestration is exaggerated in a 30 year offset because there is very little growth in the first few years after tree planting and these early years make up a far bigger proportion of the span of 30 years than they do of a span of 100 years. Hence the costs not offset are higher, with 26.4% of costs not offset at the cert equivalent rate.

Figure 4 shows the marginal social costs offset over time by a 100 year forestry offset at the certainty equivalent discount. While incremental sequestration equals marginal costs at project expiry, marginal social costs are incurred in the interim.

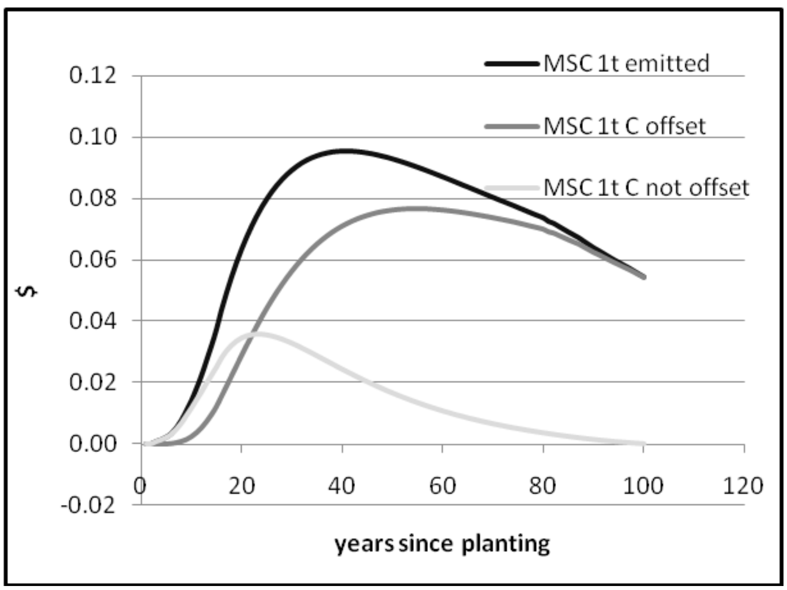

Figure 4: Carbon neutral offset where a 100 year afforestation/reforestation project offsets 1 tonne of C emitted in year 1, certainty eqivalent discount. Carbon neutrality is achieved when the forest offset project has removed 1 tonne of carbon from the atmosphere in year 100. However, social costs have been incurred in every year since since year 1 when the emissions occured.

Table 2 shows the costs not offset and offset by afforestation at various discount rates. The percentage of costs not offset in Table 2 can be employed as a factor that needs to be applied to the effectiveness of a forestry offset, at a certain discount rate, when comparing it with a reduction of carbon emissions in year 1.

100 year offset

Discount rate	Present cost 1t C emitted ($)	Cost not offset $ (%)	Cost Offset $ (%)
0	55.9	6.6 (11.8)	49.3 (88.2)
0.01	28.9	4.3 (14.7)	24.6 (85.3)
Cert Equiv	7.2	1.5 (21.4)	5.6 (78.6)
0.04	5.6	1.4 (25.8)	4.2 (74.2)

30 year offset

Discount rate	Present cost 1t C emitted ($)	Cost not offset $ (%)	Cost Offset $ (%)
0	3.5	0.8 (21.7)	2.7 (78.3)
0.01	2.5	0.5(21.4)	2.0(78.2)
Cert Equiv	1.5	0.4 (26.4)	1.5 (73.6)
0.04	1.5	0.4 (26.7)	1.0 (73.3)

Table 2: Present value and proportion of social costs not offset and offset by 100 year and 30 year afforestation/reforestation projects offsetting 1 tonne of C emitted in year 1. The profiles of the marginal social cost of C emitted and the removal of C by sequestration differ – the sequestration rate lags the rate of damage costs incurred. The table values the difference, which is "costs not offset". Higher discount rates generate higher costs not offset because of the mismatch between marginal costs and marginal sequestration rates. Costs not offset in the shorter term project are relatively high because the sequestration rate is slow in the early years.

Alternatively, the inverse of the results in column 3 of Table 2 can be expressed as the enhancement of the area of forestry necessary, *ceteris paribus*, for a forestry offset to achieve 100% cost offset or 'cost neutrality'. This rate is 1.27 for a 100 year project at the certainty equivalent discount rate, as illustrated in Figure 5, and 1.35 for a 30 year project. Cerri (2001) suggested that such an adjustment factor could be applied to sequestration, to cater for uncertainty, permanence or leakage, or to put it on an equal footing with respect to other mitigation strategies.

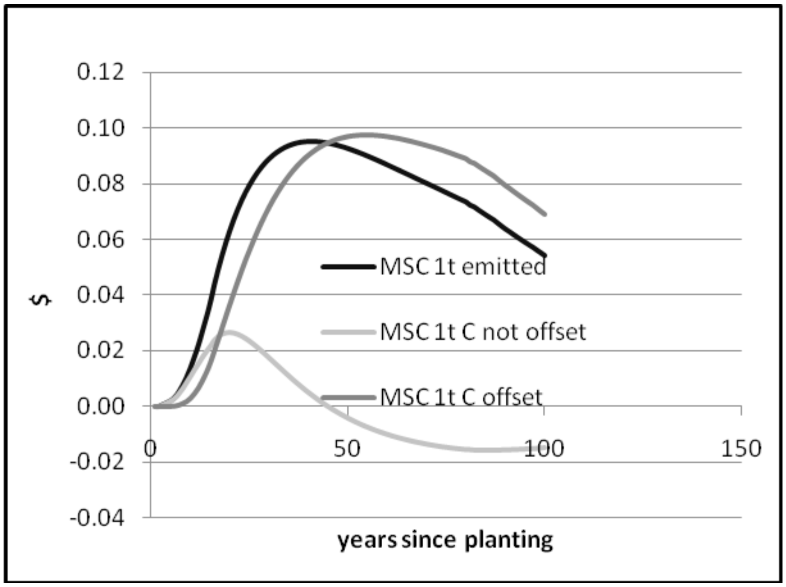

Figure 5: Cost neutral offset where a 100 year carbon neutral afforestation/reforestation project is increased in area by 27%, certainty eqivalent discount. To achieve cost neutrality in a 100-year forestry offset project an increase in forest area of 27% is required to eliminate marginal social costs.

A further result was in the comparison between not harvesting hoop pine, harvesting hoop pine – and a consequent complete accounting loss of all the above ground carbon – and harvesting where 35% of above ground carbon is sequestered in product after harvest. It was found that harvesting increases the percentage of costs not offset by 8.8% (from 21.4 to 30.2%) compared with no harvesting, at the certainty equivalent discount rate. Where an allowance is made for the carbon sequestered in product, the percentage of costs not offset increases by another 7.9% (from 30.2 to 38.1%). The effect of harvesting the hoop pine plantation, and of sequestering the product, is to delay reaching 1 tonne of C sequestered, leading to an increase in costs not covered.

5. DISCUSSION

Modeling showed that cost of 1 tonne of carbon released as a pulse to the atmosphere in the present year are not offset by an afforestation/reforestation project designed to sequester 1 tonne of carbon in future years. The costs not offset are increased where harvesting delays the overall sequestration rate.

It was found that it is the profile or shape of the MSC of a tonne of carbon emitted that is influential in determining social cost not offset rather than its present value. The rate of increase in the MSC of carbon is relatively greater than the sequestration rate in the early years and this leads to an accumulation of costs not offset. The general results for costs not offset by forestry should hold good for all locations given that sequestration profiles for unharvested plantations to a tonne of carbon are likely to be similar everywhere.

Criticism has been leveled at the sellers of voluntary offsets who disguise the fact that a forestry offset although sold *ex ante* will not in fact complete its job for 30 to 100 years. This paper shows that the cost disparities between immediate abatements and forestry offsets are more pronounced where offset projects are predicated over shorter periods. For 100 year projects it was found that at the certainty equivalent discount rate, 79% of the MSC of carbon was offset. In contrast, 74% of MSC were offset by a 30 year project. As the length of the project diminishes the proportion of emission not offset increases for a 5 year project to almost 50%, as illustrated in Figure 6. In a short term afforestation the costs not offset are greater because in the early years trees grow and sequester carbon slowly, relative to the rate of damage costs being incurred.

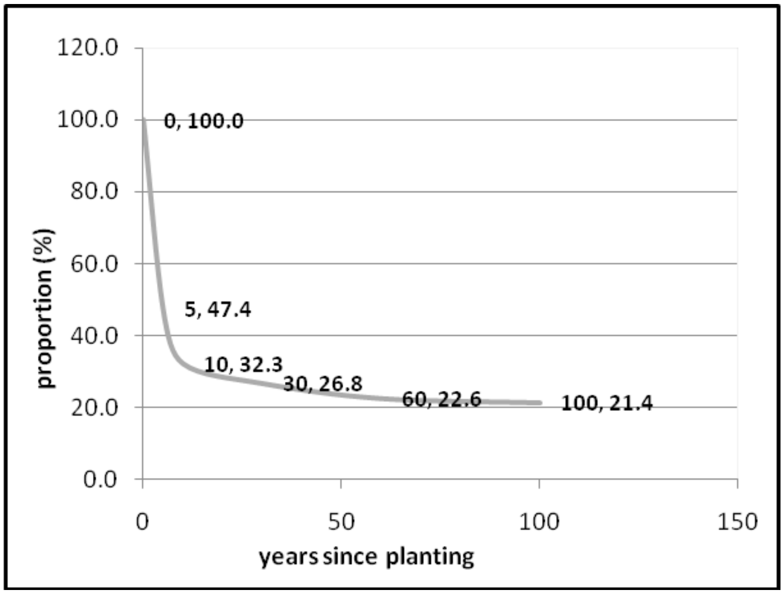

Figure 6: Proportion of present costs not offset by carbon neutral reforestation/afforestation projects of 1 tonne of C, by length of project, cartainty equivalent discount. Forestry offset projects that claim to be carbon neutral over a short term fail to cover a higher proportion of the marginal social costs of emissions than long term projects.

Another factor that is influential in determining the proportion of costs not offset in the 100 year model is the discount rate. As expected, in the 30 year model, the discount rates are less influential than for the 100 year offset.

These results were generated by using estimates of the MSC of 1t of carbon emitted in the 1994 DICE model (Nordhaus 1994), updated to year 2000 dollars. In the later (2007) DICE model, the MSC of a tonne of carbon emissions in 2005 dollars was shifted upwards considerably to a present value of $27.28 in 2005 dollars (Nordhaus 2007, Table V-9), compared with $5.87 simulated from the DICE model of 1994 in 2000 dollars. However, a proportional shifting of the curve upwards to allow for such an increase in cost makes no difference to the proportion of costs offset at different discount rates. Rather it is the shape of the MSC profile that determines the proportion of costs offset by afforestation.

Other climate models with different profiles for the MSC of carbon to the one investigated will generate different results. Earlier studies by Fearnside et al. (2000) and Moura-Costa and Wilson

(2000) accounted for CO_2 removals by forestry against the fraction of CO_2 emissions that remain in the atmosphere for 100 years after emission, as described by Houghton (1994). The decay pattern is a surrogate for marginal social costs inflicted by CO_2 emissions. The shape of the decay curve for CO_2 means that higher costs are generated in the early years than in the model of damage costs used, based on Nordhaus (1994), in which the damage costs are low initially but build over time (see Figure 1). No matter what climate model is adopted in estimating marginal social costs of emissions, it is likely that damage costs of a tonne of carbon increase more rapidly in the immediate years after release than carbon sequestration rates, and therefore that not all social costs will be covered.

5.1 Operational implications of adopting incremental crediting and debiting of carbon removed from the atmosphere by afforestation

It was shown that for forestry offset projects to avoid incurring social costs they must avoid crediting to the present the removals of CO_2e that will occur sometime in the future. Likewise, CO_2e release should occasion a debit in the year of release. If annual removals are credited (debited) according to the incremental sequestration (release) of CO_2e, then the removals (release) of CO_2e and the credits (debits) of CO_2e will match.

The incremental amount of CO_2e removed would be obtained by physical measurements of forest carbon, or its estimation according to the carbon sequestration models of afforestation – or a combination of both, where a model's estimates are validated by physical measurement.

The adoption of such incremental crediting and debiting of CO_2e removals expected in the future aids the establishment of present values of CO_2e removals needed to facilitate project financing; the present value of the credits and debits being compared with the present value of costs of the project. Moreover, the net present value of the project can then compared with that of competing investments.

5.2 Market implications of adopting incremental crediting and debiting

Our analysis supports the benefits of adopting a system where a credit is generated when an increment of CO_2e is removed by sequestration and debits are occasioned when an increment of CO_2e is emitted. Markets based on future CO_2e removal by sequestration ignore social costs that occur because of the mismatch between sequestration rates and emission costs. In practice a "pay as you go" system is accomplished in the Chicago Climate Exchange where actual CO_2e removals are traded on a spot market. In a system of contemporary crediting and debiting the role for insurance would be in hedging against the cost of debits required if the project was destroyed by fire (Cacho et al. 2003). An alternative to insurance on a case by case basis is the issue of guarantees of permanency by governments or by schemes that have large portfolios and can spread the costs of untoward debits. In this case as Sedjo and Marland (2003) point out the removals of CO_2e by forestry offsets become perfect substitutes for permanent emission removals achieved by abatement. In the case where credits receive government or other solid guarantees of permanency there is no reason why permanent forestry offset credits cannot be traded nationally and internationally.

6. CONCLUSIONS

The voluntary forestry offset is an increasingly popular instrument, marketed on the basis that contemporary greenhouse gas emissions will be offset over time by the carbon sequestered in plantations. For entities not covered by cap and trade schemes and for individuals, forestry offsets provide a mechanism through which voluntary action to mitigate GHG emissions can be taken to address climate change, or derive a marketing edge by achieving carbon neutrality. Voluntary forestry offsets are often sold *ex ante* on the basis of 30 to 100-year carbon neutrality. However, buyers are unlikely to be aware of the hidden costs of forestry offsets sold in advance of actual CO_2e removals against contemporary emissions (or indeed the hidden costs of other offsets that do not immediately achieve neutrality).

The paper demonstrates the nature and the size of 'hidden' costs – costs of climate change not offset by such forestry offset projects – compared with an immediate reduction of emissions. Results generated using updated 1994 DICE modeling show that the proportion of costs offset is insensitive to the shifting up or down of the MSC profile. Rather, the proportion of costs offset is correlated with the shape of the profile of MSC of carbon emissions over time. Other emission damages models are likely to yield similar results given the slow initial increase in annual CO_2e removals from the atmosphere by sequestration relative to marginal damage cost increases.

Recommendations are two-fold. To ensure that forestry offset schemes are cost-neutral – instead of just carbon-neutral – the actual incremental CO_2e removal should be the entity traded rather than removals in future years.

Disclosure by the seller of the estimated annual incremental removal and release (for example in the case of harvesting) of tonnes of CO_2e over the life of the offset. This allows a financier to put a present value on the expected stream of CO_2e removals by the offset, for comparison with other forestry projects and other types of offsets.

ACKNOWLEDGEMENTS

The authors acknowledge the assistance of Billy Pizer in providing data on the MSC of carbon in the 1994 DICE model in year 2000 dollars. The helpful comments of Roger Sedjo on an earlier draft are also acknowledged. However, any errors of fact or misrepresentations are the sole responsibility of the authors.

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