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Climate Change and Forest Ecosystem Sinks: Economic Analysis

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Climate Change and Forest Ecosystem Sinks: Economic Analysis

1. Introduction

Global climate change constitutes a long-term threat to the earth's ecosystems and to the way people lead their lives. Some of the most serious threats include damages to agriculture, particularly subsistence farming in developing countries, and to coastal dwellers, who could lose their homes and livelihoods as a result of flooding caused by sea level rise. While the full extent of the potential damages from climate change remains unknown, scientists have argued that action should be taken to mitigate its potentially adverse consequences.

Most scientists are convinced that the discernible rise of 0.3 to 0.6 ºC in the earth's average surface temperature over the past century (Wallace et al. 2000) is related to the significant increases in carbon dioxide (CO_2) and other greenhouse gas (GHG) concentrations in the atmosphere. Economic principle dictates that mitigation activities should be implemented as long as the marginal benefits of so doing (i.e., the damages avoided by mitigation) exceed the marginal costs of actions to reduce atmospheric CO_2. However, while the (marginal) costs of mitigation measures tend to be unclear, estimation of the (marginal) benefits is even more problematic and controversial. The damages due to climate change are expected in the more distant future and remain speculative, partly because they affect future generations and may be largely nonmarket in nature. Uncertainty about these damages (and thus the benefits of mitigation) exists in both the economic and scientific spheres.

Through the Kyoto Protocol (KP), the international community has prepared a policy response to global climate change as it relates to the emissions of GHGs. Although it is seriously flawed, the KP attempts to aid the international community in slowing or even preventing anthropogenic emissions of greenhouse gases from rising in the future. Forest ecosystem sinks, potentially cheaper than decreasing emissions from existing industries (Obersteiner, Rametsteiner and Nilsson 2001; Sohngen and Alig 2000), play an important role for some countries in their compliance with the KP.

Before examining carbon sinks as they relate to forestry activities in more detail, we outline the Kyoto Protocol and how carbon sinks have been considered in lieu of CO_2 emission reductions. Potential carbon sinks allowed in forestry are discussed, as well as a consideration of how discounting physical carbon impacts cost estimates of carbon sequestration. This is followed by a more-detailed investigation into the costs of creating carbon credits in forest ecosystems through land use, land use change, and forestry (LULUCF) activities, and their limitations. Finally, we discuss some additional difficulties related to the creation and trading of carbon offset credits.

2. Climate Change Addressed by Kyoto Protocol

As a result of international concerns over anthropogenic emissions of GHGs, the Intergovernmental Panel on Climate Change (IPCC) was formed in 1988. The IPCCs first published report in 1990 led to the signing of the United Nations' Framework Convention on Climate Change (FCCC) in Rio de Janeiro in June 1992 by 174 countries. This agreement committed industrial countries to control greenhouse gas emissions, and subsequent Conference of the Parties (COP) meetings have generated further clarification of these agreements.

In order to stabilize atmospheric concentrations of CO_2 and other GHGs, CO_2-

equivalent emissions would need to be reduced by 50% or more from 1990 levels (Coward and Weaver 2003).[1] Though falling far short of this target, by helping to craft the Kyoto Protocol at COP3 in December 1997, industrial countries agreed to reduce CO_2 emissions by an average of 5.2% from the 1990 level by 2008-2012. This is a total reduction of 250 megatons (10^6 metric tons) of carbon, denoted Mt C, per year from 1990 levels. The agreement states that the KP will come into effect 90 days after it has been ratified by 55 states, as long as the industrialized countries that ratify account for 55% of the CO_2 emitted by industrialized countries in 1990. As of June 2003, 110 countries had ratified, with developed countries' proportion of the 1990 emissions at 43.9%.[2] The United States, with 36.1% of industrial countries' emissions withdrew support for the KP during COP6 at The Hague in late 2000, citing high costs. Therefore, in order for the KP to come into effect, it is essential that Russia, accounting for 17.4% of 1990 industrial countries' CO_2 emissions, ratify the Protocol.

Environmental externalities play a large role in the KP, necessitating government action to address the associated market failure. Three economic coordination methods that attend to this market failure are outlined by economists: 1) Command and control (C&C), 2) common values and norms, and 3) market incentives. C&C consists mainly of standards (e.g., specifying fuel efficiency requirements of automobiles or the quality of insulation in new construction), bans and regulations (e.g., spelling out the amount of CO_2 a source may emit). It is well known that market instruments, such as carbon taxes or tradable emission permits (quotas), result in lower costs than C&C, because prices in the form of taxes or permits cause firms to seek the lowest cost means of reducing

[1] In this paper, we only consider CO_2, or carbon, because CO_2 is the most important anthropogenic greenhouse gas from the perspective of climate change.
[2] From the following website (accessed 27 June 2003): http://unfccc.int/resource/kpthermo.html

emissions (see Field and Olewiler 2002). International trading of CO_2 emission and offset permits, and substitution of the most economical means of reducing emissions, would allow the most economic gain, while putting a value on the environmental externalities caused by CO_2 entering the atmosphere.

With this in mind, the KP outlines the following ways for a country to meet its commitments:

- Countries can simply reduce their own emissions of GHGs to the target level, say *R* in Figure 1.
- Rather than reducing domestic CO_2 emissions to *R* (Figure 1), a country can achieve *R* by sequestering an equivalent amount of carbon in domestic terrestrial ecosystems. These activities are discussed in more detail on the following pages.
- Joint implementation (JI) is encouraged under KP Article 6. JI allows an industrial (Annex B) country to participate in emissions-reduction or carbon sequestration activities in another Annex B country (essentially in Central and Eastern Europe), thereby earning "emission reduction units" (ERUs) that are credited toward the country's own commitment.
- Under the "clean development mechanism" (CDM) of KP Article 12, an Annex B country can earn "certified emission reductions" (CERs) by funding emissions-reduction or carbon sequestration projects in a non-Annex B (developing) country. However, only afforestation and reforestation activities can be used to generate carbon uptake CERs, and their use is limited (in each year of the commitment period) to 1% of the Annex B country's 1990 (base-year) emissions.
- Finally, an Annex B country can simply purchase excess emission permits from

another Annex B country (Article 17). Emission permits in excess of what a country needs to achieve its commitment are referred to as "assigned amount units" (AAUs) that can be purchased by other countries. These are particularly important to economies in transition that easily attain their KP targets because of economic contraction and the concomitant closure of inefficient power plants and manufacturing facilities, thereby creating "hot air" (AAUs) to be sold at whatever price is available.

While the availability of a variety of emissions-reduction and carbon sequestration options should reduce the compliance costs relative to the situation where restrictions are placed only on emissions, the addition of these options complicated matters significantly. Compared to a more simplified scheme, monitoring and enforcement authorities will need more information, such as details on the supply of carbon offsets in each future year, in order to set a quota on emissions. Transaction costs of operating the trading scheme will also increase significantly.

3. Carbon sinks in lieu of emissions reduction

Negotiations since COP3 in Kyoto focused on flexibility mechanisms, most importantly Joint Implementation, the Clean Development Mechanism and International Emissions Trading. A number of parties argued that the role for terrestrial carbon sinks as replacements for emissions reductions was inadequate, so, at COP6$_{bis}$ at Bonn in July 2001, the European Union (EU) relented to a broader role for carbon sinks, mainly to appease Japan, Australia and Canada, and the United States in absentia. This permitted countries to substitute carbon uptake from LULUCF activities in lieu of greenhouse gas emissions. The IPCC (2000) estimates that biological sink options have the potential to mitigate some 100,000 Mt C between now and 2050, amounting to some 10% to 20% of fossil fuel emissions of CO_2 over the same period. When using the Marrakech Accords (agreed to at COP7 at Marrakech, Morocco, October/November 2001) as the basis for calculating the carbon offset potential of biological sinks, it is clear that terrestrial sinks have become an important means by which some countries can achieve their KP targets (see Table 1). Nearly 200 Mt of carbon credits could potentially be achieved by LULUCF activities, amounting to 80% of the 250 Mt C annual reductions that would have been required of industrial countries in 1990 but will be much higher for 2008-20012.

Under the KP, permitted terrestrial sink activities include reductions in carbon release from net land-use change and forestry in Annex B countries that had net LULUCF emissions in 1990 (Article 3.7); net removals by sinks as a result of human-induced afforestation, reforestation and deforestation (Article 3.3);[3] and net removals through changes in agronomic practices (cropland and grazing land management and revegetation actions) and from enhanced forest management (Article 3.4). The problems with terrestrial sinks are fourfold: (i) their inclusion and use under the KP is an example of political maneuvering to avoid emissions reduction, (ii) they tend to be highly ephemeral (see below), (iii) the "value" of sinks to a country is tied to the land use existing in 1990 as the base year, and (iv) carbon flux is difficult to measure. Automatic credits in the KP's first commitment period (see next section) have, however, militated against the significance of the choice of base year.

The sequestration of carbon in terrestrial sinks will also in time encounter an

[3] Not included is the COP6*bis* (COP7) provision that a country can offset in any year of the commitment period an accounting deficit under Article 3.3, say from clear cutting, with a net increase in sinks due to forest management under Article 3.4 to a maximum of 8.2 (9.0 at COP7) Mt C. This is discussed in the next section.

equilibrium, beyond which point additional net sequestration will not be possible. Most likely, before reaching this point, the economics of continuing with sequestration as a substitute for emission reductions in other areas will no longer be feasible. Therefore, for long-term reductions in total net emissions, terrestrial carbon sinks will become less important and total emissions from fossil fuels will have to be addressed. At best, in the long-term, terrestrial carbon sinks are a stop-gap measure.

4. Carbon sinks in forestry

According to the Kyoto Protocol, while not initially included in the determination of baseline carbon emissions, afforestation, reforestation and deforestation (ARD) activities need to be considered in determining 2008-2012 emissions if forest carbon sink credits are to be claimed. Afforestation refers to human activities that encourage growing trees on land that has not been forested in the past 50 years, while reforestation refers to human activities that encourage growing trees on other land that was forested but had been converted to non-forest use prior to 1990 (IPCC 2001). Afforestation and reforestation result in a credit, while deforestation (human-induced conversion of forestland to non-forest use) results in a debit. Since most countries have not embarked on large-scale afforestation and/or reforestation projects in the past decade, harvesting trees during the five-year commitment period (2008-2012) will likely result in a debit on the ARD account. Therefore, the Marrakech Accords permit countries, in the first commitment period only, to offset up to 9.0 megatons of carbon (Mt C) each year for the five years of the commitment period through (verified) forest management activities that enhance carbon uptake, but the activities can be business-as-usual (e.g., replanting, fire suppression). If there is no ARD debit, then a country cannot claim this "automatic" credit. The automatic credit amounts to the difference between mean annual increment (growth) and harvest on a (self-declared) managed forest. In Canada's case, the ARD debit for 2008-12 is estimated to be about 4 Mt C.

Some countries can also claim carbon credits from business-as-usual forest management that need not be offset against ARD debits. As a result of Marrakech, Canada can claim 12 Mt C per year, the Russian Federation 33 Mt C, Japan 13 Mt C, and other countries much lesser amounts – Germany 1.24 Mt C, Ukraine 1.11 Mt C, and remaining countries less than 1.0 Mt C. Japan expects to use forestry activities to meet a significant proportion of its KP obligation, while Canada can use forest management alone to achieve one-third of its emissions reduction target.[4]

In principle, a country should get credit only for sequestration above and beyond what occurs in the absence of C-uptake incentives, a condition known as "additionality" (Chomitz 2000). Thus, for example, if it can be demonstrated that a forest would be harvested and converted to another use in the absence of specific policy to prevent this from happening, the additionality condition is met. Carbon sequestered as a result of incremental forest management activities (e.g., juvenile spacing, commercial thinning, fire control, fertilization) would be eligible for C credits, but only if the activities would not otherwise have been undertaken (say, to provide higher returns or maintain market share). Similarly, afforestation projects are additional if they provide environmental benefits (e.g., regulation of water flow and quality, wildlife habitat) not captured by the landowner and would not be undertaken in the absence of economic incentives, such as

[4] Excluding the ARD debit, since Canada's emissions (along with those of most other countries) have risen dramatically since 1990, it needs to reduce emissions in 2008-2012 by 65.5 Mt C, with forest management to account for 18.3% of the targeted amount. Additional credits will be claimed for afforestation programs (see van Kooten 2003).

subsidy payments or an ability to sell carbon credits (Chomitz 2000).

The reason that the Kyoto negotiations have not addressed additionality explicitly is that this would disadvantage countries that have already undertaken forestry activities that generate carbon uptake benefits. For example, during the 1980s Canada invested heavily in the reforestation of not-sufficiently restocked forestland that had been harvested in previous decades but failed to generate adequate cover on its own. The business-as-usual forest management provisions of Marrakech enabled Canada to salvage some credits for these investments, rather than penalize Canada relative to countries who had not attempted to implement sustainable forestry practices at such an early date, as would be the case under a strict additionality requirement.

5. Discounting Physical Carbon

Discounting implies that a unit of carbon emitted into (or removed from) the atmosphere at a future date is worth less than if that same unit were emitted (removed) today. The idea of discounting physical carbon is anathema to many, but the idea of weighting physical units accruing at different times is entrenched in the natural resource economics literature, going back to economists' definitions of conservation and depletion (van Kooten and Bulte 2000, pp.245-47). Three approaches to discounting of carbon can be identified in the literature (Richards and Stokes 2003; Watson et al. 1996):

1. The "flow summation method" sums carbon sequestered regardless of when capture occurs. Total (discounted or undiscounted) cost of the project is divided by the total sum of undiscounted carbon to provide a cost per ton estimate.
2. Under the "average storage method" the annualized present value of costs is divided by the mean annual carbon stored through the project.

3. The "levelization/discounting method" discounts both costs and physical carbon sequestered depending on when they occur, although costs and carbon can be discounted at different rates.

One cannot obtain a consistent estimate of the costs of carbon uptake, however, unless both project costs and physical carbon are discounted, even if at different rates of discount. To illustrate why, consider the following example.

Suppose a tree-planting project results in the reduction of CO_2-equivalent emissions of 2 tC per year in perpetuity (e.g., biomass burning to produce energy previously produced using fossil fuels). In addition, the project has a permanent sink component that results in the storage of 5 tC per year for ten years, after which time the sink component of the project reaches an equilibrium. How much carbon is stored? If an annualized method (method 2) is employed, then one must use either 2 tC or 7 tC per year. Suppose the discounted project costs amount to $1,000,[5] or annualized costs of $40 if a 4% rate of discount is used. The costs of carbon uptake are then estimated to be either $20 per tC or $5.71/tC, with the latter figure often used to make the project appear more desirable. Under the first method, the cost would essentially be zero because $1,000 would need to be divided by the total amount of carbon absorbed, which equals infinity. Therefore, an arbitrary planning horizon needs to be chosen. If the planning horizon is 30 years, 110 tC are sequestered and the average cost is calculated to be $9.09 per tC; if a 40-year planning horizon is chosen, 130 tC are removed from the atmosphere and the cost is $7.69/tC. Thus, cost estimates are sensitive to the length of the planning horizon, which is not usually made explicit in most studies (see section 24.6).

[5] All monetary values are in Canadian dollars, unless otherwise indicated.

Cost estimates that take into account all carbon sequestered plus the timing of uptake can only be achieved under the third method. Suppose physical carbon is discounted at a lower rate (say, 2%) than that used to discount costs. Then, over an infinite time horizon, the total discounted carbon saved via our hypothetical project amounts to 147.81 tC and the correct estimate of costs is $6.77 per tC. Reliance on annualized values is misleading in this case because costs and carbon are discounted at different rates. If carbon is annualized using a 2% rate, costs amount to $13.53 per tC (=$40 ÷ 2.96 tC). If the same discount rate of 4% is employed for costs and carbon, the $10.62/tC cost is the same regardless of whether costs and carbon are annualized.

As Richards (1997) demonstrates, the rate at which physical carbon should be discounted depends on what one assumes about the rate at which the damages caused by CO_2 emissions increase over time. If the damage function is linear so that marginal damages are constant – damages per unit of emissions remain the same as the concentration of atmospheric CO_2 increases – then the present value of reductions in the stock of atmospheric CO_2 declines at the social rate of discount. Hence, it is appropriate to discount future carbon uptake at the social rate of discount. "The more rapidly marginal damages increase, the less future carbon emissions reductions should be discounted" (p.291). Thus, use of a zero discount rate for physical carbon is tantamount to assuming that, as the concentration of atmospheric CO_2 increases, the damage per unit of CO_2 emissions increases at the same rate as the social rate of discount – an exponential damage function with damages growing at the same rate as the social rate of discount. A zero discount rate on physical carbon implies that there is no difference between removing a unit of carbon from the atmosphere today, tomorrow or at some future time;

logically, then, it does not matter if the carbon is ever removed from the atmosphere. The point is that use of any rate of discount depends on what one assumes about the marginal damages from further CO_2 emissions or carbon removals.

The effect of discounting physical carbon is to increase the costs of creating carbon offset credits because discounting effectively results in "less carbon" with respect to a project. Discounting financial outlays, on the other hand, reduces the cost of creating carbon offsets. However, since most outlays occur early on in the life of a forest project, costs of creating carbon offsets are not as sensitive to the discount rate used for costs as to the discount rate used for carbon.

6. Forestry Activities and Carbon Offset Credits

In recent decades probably all of the net carbon releases from forests have come from tropical deforestation (since temperate and boreal forests are in approximate C balance[6]), thereby contributing to the build-up of atmospheric CO_2. Houghton (1993) estimates that tropical deforestation was the cause of 22-26% of all GHG emissions in the 1980s. This is roughly consistent with findings of Brown et al. (1993), who report that total annual anthropogenic emissions are nearly 6.0 gigatons (10^9 metric tons, Gt) of carbon, with tropical deforestation contributing some 0.6 to 1.7 Gt per year. Tropical forests generally contain anywhere from 100 to 300 m^3 of timber per ha in the bole, although much of it may not be commercially useful. This implies that they store some 20-60 tonnes of C per ha in wood biomass, although this ignores other biomass and soil organic carbon (SOC).

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[6] Some analysts believe that the failure to account fully for the sources of all of the build-up of carbon in the atmosphere, the so-called "missing carbon sink," is explained by the expanding forests (in biomass per unit area due to aging) of the northern hemisphere.

An indication of total carbon stored in biomass for various tropical forest types and regions is provided in

Table 2. The carbon sink function of soils in tropical regions is even more variable across tropical ecosystems (Table 3). This makes it difficult to make broad statements about carbon loss resulting from tropical deforestation. Certainly, there is a loss in carbon stored in biomass (which varies from 27 to 187 t C ha^{-1}), but there may not be a significant loss in SOC. While conversion of forests to arable agriculture will lead to a loss of some 20-50% of SOC within 10 years, conversion to pasture may in fact increase soil carbon, at least in the humid tropics (see Table 3). The conversion of forestland to agriculture tends to lead to less carbon storage, and a greater proportion of the ecosystem's carbon is found in soils as opposed to biomass (Table 4). To address this market failure (release of carbon through deforestation), policies need to focus on protection of tropical forests (see van Kooten, Sedjo and Bulte 1999).

Reforestation of deforested areas needs to take into account the carbon debit from harvesting trees, but it also needs to take into account carbon stored in wood product sinks (and exported carbon) and additional carbon sequestered as a result of forest management activities (e.g., juvenile spacing, commercial thinning and fire control). Even when all of the carbon fluxes are appropriately taken into account (and product sinks are not yet permitted under the KP), it is unlikely that "additional" forest management will be a cost-effective and competitive means for sequestering carbon (Caspersen et al. 2000). However, as noted above, many countries can claim carbon offset credits for forest management activities that are not additional. Global data on the potential for C uptake via forest management are provided in Table 5.

Evidence from Canada, for example, indicates that reforestation does not pay even when carbon uptake benefits are taken into account, mainly because northern forests tend to be marginal (van Kooten, Thompson and Vertinsky 1993). The reason is that such forests generally regenerate naturally, and returns to artificial regeneration accrue in the distant future. Only if short-rotation, hybrid poplar plantations replace logged or otherwise denuded forests might forest management be a competitive alternative to other methods of removing CO_2 from the atmosphere. Hybrid poplar plantations may also be the only cost-effective, competitive alternative when marginal agricultural land is afforested (van Kooten et al. 1999; van Kooten et al. 2000).

Surprisingly, despite the size of their forests and large areas of marginal agricultural land, there remains only limited room for forest sector policies to sequester carbon in the major wood producing countries (Canada, Finland, Sweden, Russia). We illustrate this using the TECAB model for northeastern British Columbia (Krcmar et al. 2001; Krcmar and van Kooten 2003). The model consists of tree-growth, agricultural activities and land-allocation components, and is used to examine the costs of carbon uptake in the grain belt-boreal forest transition zone. Estimates for the study region, extended to other regions, provide a good indication of the costs of an afforestation-reforestation strategy for carbon uptake for Canada as a whole, and perhaps for other boreal regions as well. The study region consists of 1.2 million ha, of which nearly 10.5% constitute marginal agricultural land, with the remainder boreal forest. The boreal forest is composed of spruce, pine and aspen. For environmental reasons and to comply with BC's Forest Practices Code, the area planted to hybrid poplar in the model is limited only to logged stands of aspen and marginal agricultural land. Other harvested stands are replanted to native species or left to regenerate on their own, depending on what is economically optimal. Carbon fluxes associated with forest management, wood product sinks and so on are all taken into account. An infinite time horizon is employed, land conversion is not instantaneous (as assumed in some models), carbon fluxes associated with many forest management activities (but not control of fire, pests and disease) are included, and account is taken of what happens to the wood after harvest, including decay.

Results indicate that upwards of 1.5 million tonnes of discounted carbon (discounted at 4%) can be sequestered in the region at a cost of about \$50 per tonne (nearly \$14 per t CO_2) or less. This amounts to an average of about 1.3 t ha^{-1}, or about 52 kg ha^{-1} per year over and above normal carbon uptake. If this result is applied to all of Canada's productive boreal forestland and surrounding marginal farmland, then Canada could potentially sequester some 10-15 Mt C annually via this option. This amounts to about 20% of Canada's annual KP-targeted reduction of 65.5 Mt C per year. If prices for carbon offsets (or carbon subsidies) are higher, more carbon credits will be created, but marginal costs of creating additional carbon offsets rise rapidly. This rapid increase in costs is partly due to the slow rates of growth in boreal ecosystems – boreal forests are globally marginal at best and silvicultural investments simply do not pay for the most part, even when carbon uptake is included as a benefit of forest management. Afforestation with rapid growing species of hybrid poplar provides some low-cost carbon, but thereafter marginal costs also rise rapidly (van Kooten 2000, also see below).

Globally, carbon sequestration in forest ecosystem sinks is expected to play a significant role in achieving KP targets (Table 1), but at what cost? Manley et al. (2003)

address this issue by employing 694 estimates from 49 studies for a meta-regression analysis of the average and marginal costs of creating carbon offsets using forestry. Estimates of the uptake costs are derived from three meta-regression analysis models: (1) a linear regression model where reported costs per tC are regressed on a variety of explanatory variables; (2) a model where costs are converted to a per ha basis and then regressed on the explanatory variables using a quadratic functional form; and (3) a model where per ha uptake costs are regressed on the explanatory variables using a cubic functional form. Projected costs of carbon sequestration for various scenarios are provided in Table 6.

Baseline estimates of the average costs of sequestering carbon (of creating carbon offset credits) through forest conservation in the tropics are US$11-$40 per tC. Sequestering carbon in terrestrial forest ecosystems is (generally) somewhat lower in the Great Plains than elsewhere, including the tropics. Surprisingly, costs are higher in the Corn Belt than in the tropics or Great Plains. Compared to simple conservation of existing forests, tree planting increases costs by nearly double, and agroforestry activities increase costs even more while forest management is the least costly option. Needless to say, if the opportunity cost of land is appropriately taken into account, costs are some 3.5 times higher than the baseline where such costs are assumed negligible or ignored.

When post-harvest storage of carbon in wood products, or substitution of biomass for fossil fuels in energy production, are taken into account, costs are at their lowest – some US$3.57/tC to US$31.18/tC depending on location and type of project. Accounting for carbon entering the soil also lowers costs. The reason is that the inclusion of soil and wood-product carbon sinks, or fossil fuel substitution, results in more carbon being counted for the same costs. However, some of the activities (wood product sinks) are not currently admitted under KP accounting rules, are difficult to measure and monitor (soil carbon), or are not easily implemented (biomass burning).

Finally, while the average costs reported in Table 6 are useful to decision makers, they are not truly indicative of the potential costs of creating carbon offsets because they are average estimates only. As already noted, they ignore transaction costs but they also fail to recognize that costs rise as additional carbon is sequestered in terrestrial ecosystems. This is true not only as tree planting activities gobble up agricultural land of increasing productivity, but also as an attempt is made to create more carbon offset credits on the same site. The analysis indicates that, for almost all regions, marginal costs are relatively flat, but rise very steeply thereafter. For example, in the Great Plains region, they rise slowly from nearly US$2/tC to US$10/tC by 6-7 tC per ha), but then increase very quickly thereafter.

7. Trading Terrestrial Carbon Credits

Some trading of carbon credits has now been initiated through trading networks such as the Chicago Climate Exchange (CCX) and the UK market for carbon emissions allowances (CO2e.com), but they involve only large industrial emitters (LIEs) in a limited geographic area. While others, such as the Winnipeg Commodity Exchange, have proposed the establishment of carbon trading, continuing uncertainty about whether the KP will indeed be ratified hampers efforts to stabilize these markets. Trading so far has been focused on industrial emissions and has not included agricultural or forestry offsets, although the potential for trading offsets exists with the CCX and the Winnipeg Commodity Exchange. However, before a market-based approach to carbon sinks can be applied in practice, certain market conditions will need to be met. For example, carbon offsets need to be certified, a method for seamless trading between CO_2 emissions and carbon offsets needs to be found, and an overseeing body with well-defined rules and regulations has to be established (Sandor and Skees 1999).

Carbon rights were first created in legislation in New South Wales, Australia, but they are rudimentary at best, as indicated by a judgment by Australian solicitors McKean & Park on the potential for carbon offset trading. They indicated that trading in carbon credits is unlikely to occur before 2005 because it would take that long to establish the required rules.[7] In order to buy and sell carbon offset credits, it is necessary to have legislation that delineates the rights of landowners, owners of trees and owners of carbon, because what any one of these parties does affects the amount of carbon that is sequestered and stored. Without clear legislation, buyers of carbon offsets are not assured that they will get proper credit – their claims to have met their emission reduction targets with carbon credits is open to dispute.

Landowners need clear guidelines as to how their activities would qualify for carbon offsets and how credits are to be certified so that they have a well-defined "commodity" to sell in the carbon market. In the case of afforestation of private land as a C sink, even if all conditions for trade are present, there remain concerns about the extent of landowners' willingness to plant trees for carbon uptake on large tracts of "marginal" agricultural land. Tree-planting subsidies, for example, may be inadequate because of uncertainty about future farm payments and subsidies, implications for trade, or transactions costs associated with the creation of carbon sinks on agricultural land (van

[7] Their ruling could be found on April 30, 2003, but not as of June 26, 2003, at the website: http://www.mckeanpark.com.au/html/enviroprop/epcarbtrd/epcarbnav.htm#carboncredit

Kooten, Shaikh and Suchánek 2002).

The other problem of mixed CO_2 emissions-carbon offset trading concerns the factor for converting temporary into permanent removal of CO_2 from the atmosphere. Compared to not emitting CO_2 from a fossil fuel source, terrestrial sequestration of carbon is unlikely to be permanent, particularly for carbon stored in fast-growing tree plantations on agricultural land. Yet, temporary removal of carbon is important because it (i) postpones climate change, (ii) allows time for technological progress and learning, (iii) may be a lower cost option than simply reducing CO_2 emissions, and (iv) some temporary sequestration may become permanent (Marland, Fruit and Sedjo 2001, p.262).

The ephemeral nature of terrestrial carbon uptake can be addressed in a variety of different ways. First, instead of full credits, partial credits for stored carbon can be provided according to the perceived risk that carbon will be released from the sink at some future date. The buyer or the seller may be required to take out an insurance policy, where the insurer will substitute credits from another carbon sink at the time of default. Alternatively, the buyer or seller can provide some assurance that the temporary activity will be followed by one that results in a permanent emissions reduction. For example, arrangements can be put in place prior to the exchange that, upon default or after some period of time, the carbon offsets are replaced by purchased emission reduction permits. Again, insurance contracts can be used. Insurance can also be used if there is a chance that the carbon contained in a sink is released prematurely, but it is also possible to discount the number of credits provided by the risk of loss (so that a provider may need to convert more land into forest, say, than needed to sequester the agreed upon amount of carbon). However, the risk that default will occur remains. This is especially true in the case of the KP as there is currently no requirement that countries that count terrestrial carbon uptake credits during the commitment period 2008-12 are penalized for their release after 2012.

Another method that has been proposed is to employ a conversion factor that translates years of temporary carbon storage into a permanent equivalent that can be specified. The IPCC (2000) uses the notion of ton-years to make the conversion from temporary to permanent storage.

Suppose that one-ton of carbon-equivalent GHG emissions are to be compensated for by a ton of permanent carbon uptake. If the conversion rate between ton-years of (temporary) carbon sequestration and permanent tons of carbon emissions reductions is *k*, a LULUCF project that yields one ton of carbon uptake in the current year generates only $1/k$ tons of emission reduction – to cover the one-ton reduction in emissions requires *k* tons of carbon to be sequestered for one year. The exchange rate ranges from 40 to 150 ton-years of temporary storage to cover one permanent ton, with central estimates around 50:1. The choice of exchange rate really amounts to a choice of a rate for discounting physical carbon. For example, if 1 tC is stored in a forest sink in perpetuity and physical carbon is discounted at 2%, then the discounted amount of this perpetual storage equals 50 ton-years. With a 2.5% discount rate on physical carbon, the exchange rate between CO_2 emissions and carbon offsets is 40 ton-years, while it is 100 ton-years if the discount rate is 1%. Thus, the idea of ton-years is directly linked to the rate used to discount physical carbon.

As Marland, Fruit and Sedjo (2001) note, the ton-year accounting system is flawed: ton-year credits (convertible to permanent tons) can be accumulated while trees grow, for example, with an additional credit earned if the biomass is subsequently burned in place of an energy-equivalent amount of fossil fuel (p.266). To avoid such double counting and the need to establish a conversion factor, the authors propose a rental system for sequestered carbon. A one-ton emission offset credit is earned when the sequestered carbon is rented from a landowner, but, upon release, a debit occurs. "Credit is leased for a finite term, during which someone else accepts responsibility for emissions, and at the end of that term the renter will incur a debit unless the carbon remains sequestered <u>and</u> the lease is renewed" (p.265, emphasis in original). In addition to avoiding the potential for double counting, the landowner (or host country) would not be responsible for the liability after the (short-term) lease expires. Further, rather than the authority establishing a conversion factor, the market for emission permits and carbon credits can be relied upon to determine the conversion rate between permanent and temporary removals of CO_2 from the atmosphere.

The carbon sink potential in CDM reforestation and afforestation projects exceeds that within industrial countries, making impermanence of terrestrial sinks a more pressing issue for the CDM. The issue of the impermanence of carbon sinks in CDM projects was considered by COP8 in New Delhi in October 2002. Workshops early in 2003 discussed (1) insurance coverage against the destruction or degradation of forest sinks (referred to as iCERs), and (2) the creation of "temporary" CERs (certified emission reductions) and RMUs (removal units), denoted rCER or tRMU, whereby the certified units would expire at the end of the commitment period or after a different specified period of time. When expired, these credits would have to be covered by substitute credits at that time or reissued credits if the original project were continued. Negotiations regarding definitions and modalities continue and the issue will again be addressed at COP9 in Italy, December 2003.

This method for dealing with the question of permanence does not resolve the issue of higher (transaction) costs related to contracting. It is our view that the least cost option would be to tax emissions when they occur, whether these are emissions from LULUCF activities or fossil fuel burning, and to provide a subsidy of the same amount as the tax when carbon is sequestered through some LULUCF activity. The tax revenue should be more than adequate to cover the needed subsidies.

8. Landowner willingness to create carbon sinks

A land-rich country such as Canada expects to rely on afforestation of agricultural land to meet a significant component of its KP commitment. As indicated in previous sections, there is a limit to the amount of carbon offset credits that can be claimed from forest management activities on existing forestlands. Thus, the focus will shift to afforestation of agricultural land, where the role of private landowners is more important as most forestland in Canada is publicly owned. Griss (2002) estimates that some 1.1-1.4 million ha of agricultural land in Canada can be converted to tree plantations for carbon uptake purposes, while the Sinks Table of Canada's National Climate Change Process suggested that 843,000 ha of agricultural land could be afforested. The problem of tree planting is not related to biophysical possibilities, however, but to the willingness of landowners to create carbon credits.

It is imperative to identify methods by which landowners are willing to create carbon credits and their capacity to create and market carbon offsets. Landowner preferences for different carbon sequestration methods are likely influenced by the available information and methods, institutional support and structure, and relative risk and uncertainty with regards to maintaining a profitable enterprise and remaining eligible for government programs.

Of course, farmers are generally interested in receiving carbon credits – that is, subsidies – for activities that result in soil conservation, such as a change in agronomic practices from conventional to conservation tillage or a reduction in the proportion of tillage summer fallow, both of which increase SOC by retaining organic matter. In addition, agricultural landowners may be willing to change land use by afforestation of previously cultivated land. If sinks are to be used as a flexible mechanism for meeting CO_2 emissions goals, it is important to understand landowners' incentives, motivations and preferences, as well as the transaction costs of implementing tree-planting programs. These issues have been studied using a 2000 survey of landowners in western Canada (Suchánek 2001; Suchánek, Shaikh and van Kooten 2002; van Kooten, Shaikh and Suchánek 2002).

When asked about tree planning, landowners in western Canada generally express a preference for shelterbelts rather than large-scale afforestation (Suchánek 2001). The survey also shed light on landowners' willingness to engage in carbon offset trading (see Table 7). Respondents stated that they preferred contracts with governments and large industrial emitters to change land use (or take on certain activities) over the sale of carbon credits per se (Suchánek 2001). Contracts with government and LIEs shift responsibility for the carbon offsets away from the landowner to the government or LIE. Specifically, the landowner as agent does not have an incentive to produce carbon offsets beyond switching land use (and might even cut trees for firewood), thereby adding to transaction costs as the principal needs to monitor the contract (see van Kooten, Shaikh and Suchánek 2002). Interestingly, survey respondents indicated that they preferred contract with government and LIEs, and carbon trading, to contracts with environmental NGOs (Table 7). Perhaps this is because environmental NGOs are perceived to be more likely to enforce contracts and penalize agents for acting with guile than will government or LIEs.

It is also worth noting that van Kooten, Shaikh and Suchánek (2002) found that past land use may affect the willingness of landowners to plant trees on a large scale. In particular, in regions that had previously been treed and where landowners or their forbears had incurred substantial sacrifice to carve out farms, there is a reluctance and even refusal to take part in tree planting programs.[8]

Finally, on a positive note, landowners who did indicate a willingness to participate in tree planting programs were willing to accept a payment below the opportunity cost of the next best alternative land use. Using survey data, willingness to accept compensation for block tree planting was estimated to be between \$35.39 and \$55.02 per acre, while the opportunity costs of land were calculated to be \$42.00/ac for pasture land, \$47.25/ac for land in hay and \$71.85/ac for land in grain production (Suchánek, Shaikh and van Kooten 2002). It is likely that forested land provides benefits to some landowners that are not captured in the market. These include benefits from greater scenic diversity, increased wildlife habitat, water conservation and soil conservation.

[8] Forestland continues to be cleared for agriculture. For the 2-year period 1995-1997, for example, 0.7% of Alberta's forestland (some 200,000 ha) was converted to agriculture (Alberta Environmental Protection 1998).

9. Conclusion

While terrestrial carbon sinks do have potential to sequester carbon from the atmosphere, they are not the "golden policy bullet" that many people are expecting, and they are more likely to be a distraction from the real goal of reducing fossil fuel CO_2 emissions. Because of their temporary nature, transaction costs to maintain the sinks are ignored. The use of sinks as a replacement for reducing CO_2 emissions during the earlier KP commitment periods may make it more difficult to reduce emissions in the future, when sinks are nearing their economic maximum level, because of the lack of investment in technology. The uncertainties with respect to carbon trading, additionality and leakage of projects, and the actual costs of sequestration are also of concern. Therefore, although carbon sinks have some value, that value is likely less that is often purported via the international agreements.

Abbreviations

AAUs – assigned amount units – emission permits in excess of what a country needs to achieve KP commitment. Can be purchased by other countries.

ARD – Afforestation, reforestation, and deforestation

CDM – Clean Development Mechanism, where an Annex B country earns "certified emission reductions" by funding emission reduction or carbon sequestration projects in non-Annex B (developing) countries

CER – certified emission reductions

iCER – CERs for which insurance coverage shall be maintained for a specified period

rCER – removal CER, which is related to a tRMU

COP – Conference of Parties, followed by a number to indicate which meeting is referenced (e.g. COP6)

ERU – emission reduction unit – earned as credit for a country that participates in JI activities in another country

EU – European Union

FCCC – the United Nation's Framework Convention on Climate Change, signed in Rio de Janeiro in 1992

GHG – greenhouse gas

IPCC – Intergovernmental Panel on Climate Change

JI – Joint Implementation, where an Annex B country participates in emissions reduction or carbon sequestration in another Annex B country

KP – Kyoto Protocol

LIE – large industrial emitter of greenhouse gases

LULUCF – land use, land use change and forestry

NGO – non-governmental organization

RMU – removal unit for carbon sinks

tRMU – temporary RMU

SOC – soil organic carbon

Other Definitions

Annex I – countries listed in Annex I of the United Nations' Framework Convention on Climate Change of 1992: Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom and the United States. These agreed to limit GHG emissions to the 1990 level by 2000.

Annex B – countries listed in Annex B of the Kyoto Protocol of December 1997 include those of Annex I minus Belarus and Turkey. These countries agreed to achieve self-imposed limits on GHG emissions by 2008-12 relative to 1990.

Carbon offsets – carbon credits created via an approved terrestrial sink activity, and referred to as RMUs.

Commitment period – the KP commits countries to attain self-declared emission control targets by 2008-12. This period is referred to as the first commitment period in anticipation of successful future negotiations to limit CO2 emissions even further by targeted dates.

Economic efficiency – maximizing aggregate economic benefits which consist of consumer plus producer surpluses

Tables

Table 1. Potential Role of Terrestrial Carbon Sinks in Meeting KP First Commitment Period Targets, Based on Marrakech Accords (Mt C per year)

Item	Annex I	Rest of Annex B	Total Annex B
KP Article 3.3 (ARD) net increase in sinks	12.28	0.00	12.28
Maximum sinks due to forest management[a]	59.28	38.59	97.87
Increase in sinks due to agricultural activities	29.95	3.61	33.56
Maximum use of sinks under KP Article 12 (CDM)	34.96	14.87	49.83
Total estimated potential of sinks to meet KP target	**136.47**	**57.07**	**193.54**

[a] At COP7, Russia increased its maximum sink level from 17.63 Mt C to 33.00 Mt C, thereby increasing the total here from 23.22 to 38.59. Not included is the annual 0.8 Mt C increase in permitted credits attributable to forest management as an offset against ARD debits during the commitment period, when comparing Bonn (COP6bis) with Marrakech (COP7).

Source: Missfeldt and Haites (2001) and author's own calculations

Table 2. Carbon Content of Biomass, Various Tropic Forests and Regions

Country/Forest	Wet Tropical	Dry Tropical
Africa	187 t C ha^{-1}	63 t C ha^{-1}
Asia	160 t C ha^{-1}	27 t C ha^{-1}
Latin America	155 t C ha^{-1}	27 t C ha^{-1}

Source: Papadopol (2000)

Table 3. Depletion of Soil Carbon following Tropical Forest Conversion to Agriculture

Soil Carbon in Forest	New Land Use	Loss of Soil Carbon with New Land Use
Semi-arid region		
15-25 t C ha^{-1}	Shifting cultivation (arable agriculture)	30-50% loss within 6 years
Sub-humid region		
40-65 t C ha^{-1}	Continuous cropping	19-33% loss in 5-10 years
Humid region		
60-165 t C ha^{-1}	Shifting cultivation	40% loss within 5 years
	Pasture	60-140% of initial soil C

Source: adapted from Paustian et al.(1997)

Table 4. Total Carbon in Tropical Ecosystems by Sink, Percent[a]

Land Use	Tree	Understory	Litter	Root	Soil
Original Forest	**72**	**1**	**1**	**6**	**21**
Managed & logged over-forest	72	2	1	4	21
Slash & burn croplands	3	7	16	3	71
Bush fallow	11	9	4	9	67
Tree fallow	42	1	2	10	44
Secondary forest	57	1	2	8	32
Pasture	<1	9	2	7	82
Agroforestry & tree plantations	49	6	2	7	36

[a] Average of Brazil, Indonesia and Peru

Source: Woomer et al. (1999)

Table 5. Global Estimates of the Costs and Potential Carbon that can be Removed from the Atmosphere and Stored by Enhanced Forest Management from 1995 to 2050

Region	Practice	Carbon Removed & Stored (Gt)	Estimated Costs ($US $\times 10^9$)
Boreal	Forestation[a]	2.4	17
Temperate	Forestation[a]	11.8	60
	Agroforestry	0.7	3
Tropical	Forestation[a]	16.4	97
	Agroforestry	6.3	27
	Regeneration[b]	11.5 - 28.7	44 - 99
	Slowing-deforestation[b]	10.8 - 20.8	
TOTAL		**60 – 87**	

[a] Refers primarily to reforestation, but this term is avoided for political reasons.
[b] Includes an additional 25% of above-ground C to account for C in roots, litter, and soil (range based on uncertainty in estimates of biomass density)
Source: Adapted from Watson et al. (1996, pp.785, 791)

Table 6. Projected Costs from Three Models of Creating Carbon Offsets through Forestry Activities, 2002 (US$ per tC)

Scenario	Model		
	Linear	Quadratic	Cubic
Baseline (Tropics/Conservation)	11.06	30.22	40.44
<u>Tropics</u>			
Planting	17.98	55.79	77.46
Agroforestry	25.39	63.81	87.79
Forest Management	10.57	25.38	33.33
Soil Sink	8.02	14.64	16.29
Fuel Substitution	5.51	18.96	24.45
Product Sink	3.57	10.92	13.35
Opportunity Cost of Land	40.42	109.81	140.58
<u>Great Plains</u>			
Conservation	13.91	23.99	30.91
Planting	22.61	44.29	59.20
Agroforestry	31.93	50.66	67.09
Forest Management	13.30	20.15	25.47
Soil Sink	10.09	11.62	12.45
Fuel Substitution	6.94	15.05	18.68
Product Sink	4.49	8.67	10.20
Opportunity Cost of Land	50.83	87.18	107.44
<u>Corn Belt</u>			
Conservation	17.37	33.92	43.30
Planting	28.24	62.63	82.93
Agroforestry	39.88	71.64	93.99
Forest Management	16.61	28.50	35.68
Soil Sink	12.60	16.43	17.44
Fuel Substitution	8.66	21.29	26.17
Product Sink	5.61	12.26	14.29
Opportunity Cost of Land	63.50	123.27	150.51
<u>Other Regions</u>			
Conservation	18.41	39.92	51.58
Planting	29.94	73.70	98.79
Agroforestry	42.28	84.30	111.96
Forest Management	17.61	33.53	42.50
Soil Sink	13.36	19.34	20.77
Fuel Substitution	9.18	25.05	31.18
Product Sink	5.95	14.42	17.03
Opportunity Cost of Land	67.31	145.07	179.29

Source: (Manley et al. 2003)

Table 7. Western Canadian Farmers' Ranking of Means for Establishing Carbon Sinks

Governance structure	Normalized Rank
Tree-planting contracts with government/state agency	1.00
Tree-planting contracts with private firms (large CO_2 emitters)	0.87
Sell carbon credits in markets established to allow trade	0.71
Tree-planting contracts with ENGOs	0.44

Source: van Kooten, Shaikh and Suchánek (2002)

Figures

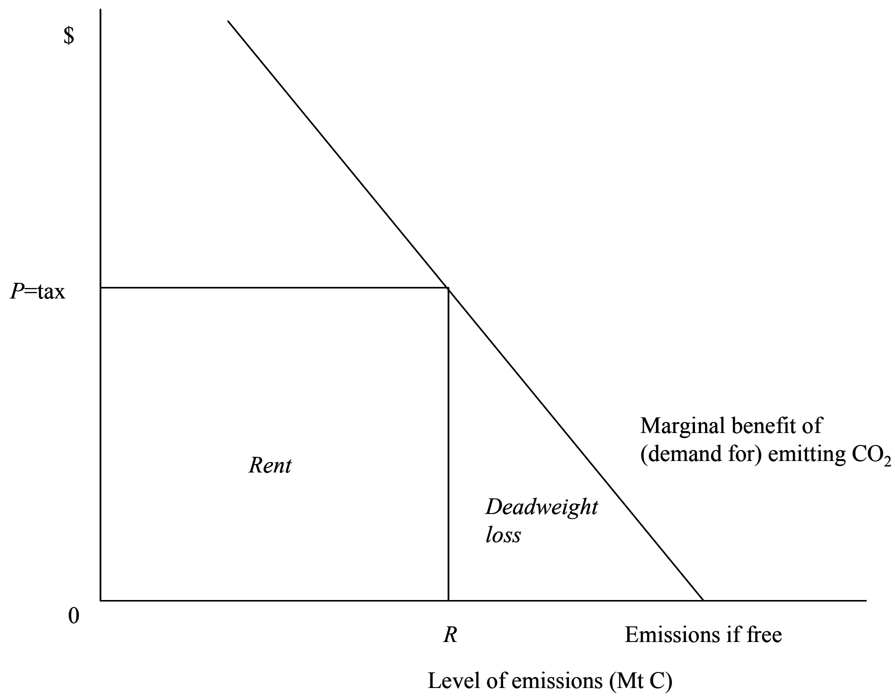

Figure 1. Controlling CO_2 Emissions using Economics Incentives

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