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Economics of Forest and Agricultural Carbon Sinks

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Economics of Forest and Agricultural Carbon Sinks[1]

As a result of the Kyoto Protocol (KP) and its so-called 'flexibility mechanisms', climate change and mechanisms to mitigate its potential effects have attracted considerable economic and policy attention. A major reason for this attention is that the KP has a complex set of instruments that enable countries to achieve emissions reduction targets in a wide variety of ways, some of which are unlikely to lead to real, long-term reductions in greenhouse gas emissions. One purpose of this chapter, therefore, is to provide an overview of economic reasoning applied to climate change and to illustrate how terrestrial carbon uptake credits (offset credits) operate within the KP framework. Attention is focused on the feasibility of terrestrial carbon sinks to slow the rate of CO_2 buildup in the atmosphere (Beattie, Bond and Manning 1981).

I also examine the results of several empirical studies into the costs of carbon uptake in agricultural ecosystems and by forestry activities. For example, Manley et al. (2004) examined the costs of creating soil carbon sinks by switching from conventional to zero tillage. The viability of agricultural carbon sinks was found to vary by region and crop, with no-till representing a low-cost option in some regions (costs of less than \$10/tC), but a high-cost option in others (costs of \$100-\$400/tC). A particularly relevant finding is that no-till cultivation may store no carbon at all if measurements are taken at sufficient depth. In some circumstances no-till cultivation may yield a 'triple dividend' of carbon storage, increased returns and reduced soil erosion, but in many others creating carbon offset credits in agricultural soils is not cost effective because reduced tillage

[1] Prepared for **Climate Change and Managed Ecosystems** edited by by J.S. Bhatti, R. Lal, M. Apps and M. Price. Baton Roca, FL: CRC Press.

practices store little or no carbon. This is particularly the case in the Great Plains. In another study, van Kooten (2004) review estimates from 55 studies of the costs of creating carbon offsets using forestry. Lowest costs of sequestering carbon are through forest conservation, while tree planting and agroforestry activities increase costs by more than 200%. The use of marginal cost estimates instead of average cost results in much higher costs for carbon sequestration, in the range of thousands of dollars per tC, although few studies used this more-appropriate method of cost assessment.

I conclude by making the case that, while there remains a great potential for carbon sinks, more attention needs to be paid to post-harvest. In the above research, post harvest storage of carbon in wood products yielded much lower cost estimates. Yet, the study of post harvest uses of biomass remains an area that requires greater attention by economists.

1. ECONOMIC INSTRUMENTS TO ADDRESS CLIMATE CHANGE AND THE KYOTO PROTOCOL MECHANISM

Economists generally prefer economic incentives over command-and-control regulation, because market incentives are usually better suited for achieving environmental objectives at lower cost than government regulations. In the context of climate change, economic incentives induce firms to adopt technical changes that lower the costs of reducing CO_2 emissions, because they can then sell permits or avoid buying them, or avoid paying a tax. Further, market instruments provide incentives to change products, processes and so on, as marginal costs and benefits change over time. Because firms are always trying to avoid the tax or paying for emission rights, they tend to respond quickly to technological change.

Whether a quantity or price instrument is chosen should not matter. This can be illustrated with the aid of Figure 1. Restricting the amount of CO_2 emissions (focusing on quantity) should lead to the same outcome as an emissions tax (focusing on price). The carbon tax (*P* in Figure 1) determines the level of emissions; if emissions are restricted to *C** and permits are issued in that amount, the permit price should be *P*, or the same as the tax. The state can choose the tax level (price) or the number of emission permits (quantity), but if all is known the outcome will be the same – emissions will be reduced to *C**.

<Insert Figure 1 about here>

When abatement costs and/or benefits are uncertain, however, picking a carbon tax can lead to the 'wrong' level of emissions reduction, while choosing a quantity can result in a mistake about the forecasted price that firms will have to pay for auctioned permits (Weitzman 1974). Such errors have social costs. If the marginal cost of abatement curve is relatively steep but the marginal benefit of abatement rather flat (i.e., damages accumulate slowly), as is likely the case with climate change, the costs of relying on permit trading are much higher than those associated with carbon taxes (Pizer 1997; Weitzman 2002; Weitzman 1974). However, as discussed below, the KP relies neither on taxes nor pure emissions trading.

Regardless of how emissions are curtailed, doing so creates a wedge between the marginal costs of providing emission permits (which are effectively zero) and the price at which they sell in the market. This wedge is a form of scarcity rent (van Kooten and Bulte 2000), with the total unearned rent equal to the restricted level of emissions multiplied by their price (Figure 1). The rent represents the capitalized value of the right to emit CO_2, which had previously been free. With a tax, the government captures the rent. With a tradable emissions scheme, the government captures the rent only if emission rights are auctioned off; if emission rights are grandfathered (given to emitters on the basis of current emissions, say), the rent is captured by extant emitters. Those lucky enough to receive tradable emission permits experience a windfall. As a result, governments will be subject to tremendous lobbying pressure in their decision regarding the allocation of permits. Countries that have done the most to reduce emissions in the past may lose relative to ones that made no similar efforts; firms that are high-energy users may benefit relative to those firms that invested in energy savings technology.

Notice that the rent constitutes an income transfer and not a cost to society of reducing emissions. The authority can distribute the rent any way it sees fit by the method it chooses to allocate emission rights. It can even distribute the rent in ways that provide certain emitters with windfalls not provided other emitters, if this is what is needed to make the scheme more palatable. However, it can do little about the costs of reducing CO_2-equivalent emissions. Costs are given in Figure 1 by the triangle labeled 'deadweight loss', which might be considered the minimum cost to society of achieving the emissions target C^*. Costs may well be higher if the wrong policies are implemented. In any event, it is this cost that needs to be compared to the benefits of achieving C^*.

Contrary to the acid rain case (SO_2 emissions from power plants) where emission trading enjoyed great success, the marginal costs of achieving a specified emissions reduction target are not well known. Thus, some economists favor a carbon tax to ensure that costs do not spin wildly out of control. Yet, the international community, fascinated perhaps by the success in reducing SO_2 emissions, opted for a quantity instrument. Two types of quantity instrument are available: permit (allowance) trading and credit trading. They are not the same thing, and we review the merits of each and discuss their implications with respect to carbon sinks.

Under *permit trading* (also known as allowance trading), the authority establishes an aggregate emissions cap (say C^* in Figure 1) and issues emission allowances (permits) of that amount for use and/or trading. This is euphemistically known as 'cap and trade'. Under *credit trading*, each large industrial emitter (each major source of emissions) is required to meet an emissions target that is usually but not necessarily set below current emissions. The current level of emissions is often referred to as the 'baseline'. Emission reductions in excess of the pre-specified target (reductions in excess of baseline minus target emissions) can be certified as tradable credits. However, other types of credits can also be certified at the discretion of the authority. Importantly, there is no overall cap on emissions and, hence, no guarantee that emissions will not exceed the target.

The Kyoto process began with emission reduction targets and only afterwards considered instruments for implementation. Taxes were rejected as politically infeasible and difficult to coordinate, although individual countries could employ taxes as they saw fit. However, most countries opted not to rely on taxes; for example, Canada's implementation plan makes no mention of taxes whatsoever. Rather than make the effort to 'sell' citizens on the notion of carbon taxes, perhaps by reducing income taxes and demonstrating the benefits of the so-called 'double-dividend' (Bovenberg and Goulder

1996; Parry, Williams and Goulder 1999), countries opted for a hodge-podge of means for meeting targets that included possibilities for credit trading. Credit trading of emissions and carbon offsets (e.g., carbon sequestration in sinks as permitted under KP Articles 3.3, 3.4 and 3.7) is seen as a method of achieving KP targets cheaply and efficiently, and individual countries are encouraging the establishment of emission trading schemes that include offsets.

2. TERRESTRIAL CARBON SINKS: ISSUES

Land use, land-use change and forestry (LULUCF) activities can lead to carbon offset credits or debits. Such offsets have taken on great importance under the KP despite the EU-15's initial opposition to their inclusion. As a result, carbon offsets need to be taken into account in any credit trading scheme. The Marrakech Accords to the KP lay out the basic framework for including offset credits (IPCC 2001). Tree planting and activities that enhance tree growth clearly remove carbon from the atmosphere and store it in biomass, and thus should be eligible activities for creating carbon offset credits. However, since most countries have not embarked on large-scale afforestation and/or reforestation projects in the past decade, harvesting trees during the five-year KP commitment period (2008–12) will cause them to have a debit on the afforestation-reforestation-deforestation (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 2008–12 through (verified) forest management activities that enhance carbon uptake (although the amount of carbon sequestered is not verified). If there is no ARD debit, then a country cannot claim the credit. In addition, some countries are able to claim carbon credits from business-as-usual forest management that need not be offset against ARD debits. Canada can claim 12 Mt C per year, the Russian Federation 33 Mt C, Japan 13 Mt C, and other countries much lesser amounts. These are simply 'paper' claims as there is no new net removal of CO_2 from the atmosphere.

In addition to forest ecosystem sinks, agricultural activities that lead to enhanced soil organic carbon and/or more carbon stored in biomass can be used to claim offset credits. Included are revegetation (establishment of vegetation that does not meet the definitions of afforestation and reforestation), cropland management (greater use of conservation tillage, more set asides) and grazing management (manipulation of the amount and type of vegetation and livestock produced).

One problem with agricultural and to a lesser extent forestry carbon sequestration activities is their ephemeral nature. One study found, for example, that all of the soil organic carbon stored as a result of 20 years of conservation tillage was released in a single year of conventional tillage (Lewandrowski et al. 2004). Likewise, there is concern that tree plantations will release a substantial amount of their stored carbon once harvested, which could happen as soon as five years after first planting due to the use of fast-growing hybrid species. Payments that promote direct changes in land uses for the purpose of carbon sequestration often result in indirect changes in land use that release CO_2, something known as a 'leakage'. Further, carbon flux from LULUCF activities is extremely difficult to measure and monitor over time, increasing the transaction costs of providing carbon offset credits. Despite these obstacles, many scientists remain optimistic about the importance of terrestrial carbon sinks (IPCC 2000).

In this section, we examine some issues related to the inclusion of carbon offset credits in a larger emissions trading scheme. Some of these issues are related to the trading scheme itself, but others relate to the costs and benefits of creating offsets – the economic efficiency of relying on carbon sink offsets rather than CO_2-emissions reduction.

A. ADDITIONALITY, MONITORING AND LEAKAGES

In principle, a country should get credit only for carbon uptake over and above what occurs in the absence of carbon-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 carbon 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 carbon incentives.

It is often difficult to determine whether an activity is truly additional. For example, farmers have increasingly adopted conservation tillage practices because costs of controlling weeds (chemical costs) have fallen, fuel and certain machinery costs have risen, and new cultivars reduce the impact of yield reductions often associated with conservation tillage. If farmers adopt conservation tillage practices in the absence of specific payments for carbon uptake, they should not be provided with carbon offset credits. If zero tillage is adopted simply because it is profitable to do so, the additionality condition is not satisfied and no carbon credits can be claimed. Likewise, farmers who have planted shelterbelts should not be provided carbon subsidies unless it can be demonstrated that such shelterbelts are planted for the purpose of sequestering carbon and would not otherwise have been planted.

In addition to determining whether a LULUCF project is indeed additional, it is necessary to determine how much carbon is actually sequestered and for how long. Measuring carbon uptake is a difficult task and can be even more difficult if the carbon sink is short lived. Monitoring and enforcement are costly and measurement is an inexact science in the case of carbon uptake in terrestrial ecosystems. Research studies reporting differences in soil organic carbon (SOC) between conventional and conservation tillage practices find that these depend on soil type, depth to which soil carbon is measured, and other factors (Manley et al. 2004). But if SOC needs to be constantly measured and monitored, as appears likely for ephemeral sinks (see below), transaction costs could greatly exceed the value of the carbon sequestered.[2]

The onus of establishing whether or not certain agricultural practices or tree planting (forest management) programs should receive carbon offset credits extends beyond simply examining the direct LULUCF impact. The direct impact relates to the carbon flux at the site in question. The indirect impact refers to the changes in CO_2 emissions elsewhere that are brought about by the LULUCF activity. In particular, there may be leakages caused by changes/shifts in land use elsewhere and/or changes in emissions, and these need to be set against the direct impacts. Large-scale tree planting

[2] Little research has been done on estimating transaction costs, although a study by van Kooten, Shaikh and Suchánek (2002) demonstrates that they can be a serious obstacle to adoption of tree planting programs.

programs in Canada, for example, might reduce future lumber prices, thereby causing U.S. forest landowners to harvest trees sooner, or convert land from forestry to agriculture, in anticipation of falling stumpage prices (see, for example, Adams et al. 1993). This causes an increase in CO_2 emissions that needs to be offset against the gain in carbon uptake from the original afforestation project. Likewise, subsidies to stimulate ethanol production will increase grain prices, thereby providing an impetus to convert land from forest to agriculture at the extensive margin and to increase use of chemical and fuel inputs that emit CO_2-equivalent gases at the intensive margin. Further, as Lewandrowski et al. (2004) note, payments to get a landowner to adopt no tillage on one field may be accompanied by the conversion of another field from zero to conventional tillage by the same landowner. Such leakages could substantially offset a project's direct gains in carbon uptake. They also increase the costs of creating carbon offset credits, making them less attractive relative to emission reduction credits.

B. DISCOUNTING PHYSICAL CARBON

By discounting carbon, one acknowledges that it matters when CO_2 emissions or carbon uptake occurs – carbon sequestered today is more important and has greater potential benefits than that sequestered at some future time. Yet, the idea of discounting physical carbon is anathema to many who would discount only monetary values. 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 (Ciriacy-Wantrup 1968). One cannot obtain consistent estimates of the costs of carbon uptake unless both project costs and physical carbon are discounted, even if different rates of discount are employed for costs and carbon. To illustrate why, consider the following example.

Suppose a tree-planting project results in the reduction of CO_2-equivalent emissions of one 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 6 tC per year for ten years, after which time the sink component of the project reaches an equilibrium. How much carbon is stored? If all costs and uptake are put on an annual basis, we need to determine how much carbon is actually sequestered per year? Is it 1 tC or 7 tC per year? Clearly, 7 tC are sequestered for the first ten years, but only 1 tC is sequestered annually after that time. Carbon sequestration, as stated on an annual basis, would either be that experienced in the first ten years (7 tC per year) or in the infinite number of years to follow (1 tC per year). Suppose the discounted project costs amount to $1,000; these include the initial site preparation and planting costs plus any annual costs (maintenance, monitoring, etc), appropriately discounted to the current period. If a 4% rate of discount is used, costs are $40 per year – the amount that, if occurring each year in perpetuity, equals $1000 in the current period. The costs of carbon uptake are then estimated to be $5.71 per tC if it is assumed that 7 tC is sequestered annually and $40/tC if 1 tC is assumed to be sequestered each year. The former figure might be cited simply to make the project appear more desirable than it really is.

Suppose instead we intend to divide the $1000 cost by the total undiscounted sum of carbon that the project sequesters. Since the amount of carbon sequestered is 7 tC per year for 10 years, followed by 1 tC per year in perpetuity, the total carbon absorbed is infinite, and the cost of carbon uptake would essentially be zero. To avoid an infinite sum of carbon uptake, an arbitrary planning horizon needs to be chosen. If the planning horizon is 30 years, 90 tC are sequestered and the average cost is calculated to be $11.11 per tC; if a 40-year planning horizon is chosen, 100 tC are removed from the atmosphere and the cost is $10.00/tC. Thus, cost estimates are sensitive to the length of the planning horizon, which is not always made explicit in studies.

Consistent cost estimates that take into account all carbon sequestered plus the timing of uptake can only be achieved by discounting both costs and physical carbon. Suppose physical carbon is discounted at a lower rate (say, 2%) than that used to discount costs (4%). Then, over an infinite time horizon, the total discounted carbon saved via our hypothetical project amounts to 112.88 tC and the correct estimate of costs is $8.86 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 $17.70 per tC (=$40 ÷ 2.26 tC). If the same discount rate of 4% is employed for costs and carbon, the cost is $30.20/tC (or $8.24 per t CO_2) and it is the same regardless of whether costs and carbon are annualized.

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 (Herzog, Caldeira and Reilly 2003; Richards 1997). 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" (Richards 1997, 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' attributable to a project. Discounting financial outlays, on the other hand, reduces the cost of creating carbon offsets. 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.

C. CREDIT TRADING

Perhaps the most important market-based initiative with respect to terrestrial carbon sinks is the establishment of the exchange-traded markets for carbon uptake credits. Through exchange landowners could potentially profit from practices that enhance SOC or carbon in vegetation. But studies indicate that this will require a well-functioning design mechanism for implementing carbon trading. Indeed, emission trading schemes fail not because of a lack of interest, but from a breakdown in necessary economic and market conditions, such as imperfect information and high transactions costs. The Chicago Climate Exchange (CCX) was launched early in 2003 as the first North American central market exchange to allow trading of CO_2 emissions between industry and agriculture. Its purpose is to provide price discovery, which will clarify the debate about the costs of emissions reduction and the role of carbon sinks. Carbon sequestration through no-till farming, grass and tree plantings, and other methods will enable farmers to sell carbon credits on the CCX. However, the prices that are 'discovered' may not reflect the true costs to society because the CCX is a credit trading scheme as opposed to an allowance trading scheme (Woerdman 2002).

Trading is also possible through CO2e.com, a UK exchange for carbon emission offsets that began in April 2002 and subsequently went global.[3] Initially, it provided a market for emissions trading for British firms that held agreements to cut emissions under the UK's climate change levy scheme, for which they receive tax rebates on energy use. Companies failing to meet targets are able to buy credits to offset their above-target emissions. Companies participating in the exchange are hedging their exposure to losing a tax rebate on energy use. As a result, by mid July 2003, carbon was trading for as much as US$10.50 per t CO_2, with transaction sizes in the range of 5,000 to 15,000 tonnes.

CO2e.com now functions as an exchange for trading CERs from Joint Implementation and Clean Development Mechanism projects, and carbon offset activities. Countries and firms can purchase (sell) CERs and removal units (carbon offsets) for delivery in 2010. Trades for delivery in 2010 have been occurring at around US$4.50-$5.50 per tCO_2-e, with trades involving 2 to 10 Mt CO_2. Not surprisingly, Canada has thus far been the largest buyer as a result of its commitment to domestic large

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[3] Discussion of CO2e.com is based on http://www.co2e.com/trading/MarketHistory.asp (viewed 7 July 2004).

industrial emitters that they would not have to pay more than $C15.00 per tCO_2 for reducing emissions. CO2e.com also anticipates that it will be able to arrange trades in carbon offsets through the emissions exchange newly established by the European Union.[4] It is not clear, however, how the exchange rate between sink offsets and emission reductions will be established (see subsection D below).

A number of other traders in carbon credits can be found on the internet, including eCarbontrade (www.ecarbontrade.com/ ECIAbout.htm), the Kefi-exchange (http://www.kefi-exchange.com/), and CleanAir Canada (http://www.cleanaircanada.org), which is government backed. The Kefi-Exchange is a private exchange begun in Alberta by traders with experience in the trading of various commodities on-line, including electricity. However, a CO_2 emissions-trading market appears to present a greater challenge. As pointed out on the Kefi-Exchange website:

> "The on-going uncertainty of the global endorsement of the Kyoto Protocol has left the future of the KEFI Exchange in limbo. … [T]he actual operation of the exchange cannot proceed without some clarity in the regulation of emissions. As a result of the current stalemate, the KEFI Exchange has opted to move to a 'stand down' mode pending a clearer determination of the directions to be taken in Alberta and the rest of Canada in respect to emission reductions."[5]

Commodity markets, such as the Winnipeg Commodity Exchange, are also looking into trading carbon emissions and carbon sink credits. With all the problems, it is

[4] See http://europa.eu.int/comm/environment/climat/emission.htm (viewed 7 July 2004).

[5] This quote was originally viewed on 8 May 2003, but had not been removed as of 7 July 2004. This is a telling observation about the difficulty of establishing exchanges that take carbon offset trading seriously.

not surprising that trades are few and far between, especially those that involve carbon offsets. Indeed, Australian solicitors McKean & Park, who were asked to make a judgment on the proposed Australian trading system, indicate that any trading in carbon credits is unlikely to occur before 2005. Tietenberg et al. (1999) also indicate that there are a significant number of obstacles to overcome before trading can occur, including most importantly a means of verifying emission-reduction and carbon sequestration claims.

Clearly, a market-based approach to carbon sinks will be effective only in the presence of certain market conditions. For example, 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. Carbon offsets need to be certified, and an overseeing (international) agency with well-defined rules and regulations is needed. It would appear that, currently, those participating in the few exchanges that have been established are doing so despite the risk that carbon offset credits may not deliver because of their ephemeral nature.

D. THE EPHEMERAL NATURE OF SINKS

Compared to not emitting CO_2 from a fossil fuel source, terrestrial sequestration of carbon is unlikely to be permanent.[6] Kyoto is in the process of developing policy for addressing the non-permanence of terrestrial carbon uptake. Some nations want emissions and removals to be treated identically, so that the removal of a unit of carbon results in a credit just as a reduction in emissions. Does it matter whether the 'removal' from the atmosphere is the result of biological sequestration or a consequence of leaving a CO_2-equivalent unit of fossil fuel in the ground? Some argue that, by leaving fossil fuels in the ground, this only delays their eventual use and, as with carbon sequestered in a terrestrial sink, results in the same obligation for the future (Herzog, Caldeira and Reilly 2003). Others argue that there is an asymmetry between carbon uptake in a sink and emissions reduction (leaving fossil fuel in the ground).[7] Whatever the case, carbon sequestered in a sink creates a liability for the future that is not the case with an emissions reduction. As a result, a country will under the KP need to ensure that carbon entering a sink in the 2008-12 commitment period is somehow covered (or still in place) in a second, third and later commitment period. Currently, this is not a serious problem for a country because the liability can be factored into a country's self-selected future commitment to emission reductions.

The ephemeral nature of terrestrial carbon uptake can be addressed by providing partial instead of full credits for stored carbon according to the perceived risk that carbon will be released from the sink at some future date. The buyer or the seller may be

[6] This is not to suggest that carbon sinks are not worthwhile. Temporary removal of carbon helps postpone climate change, buys time for technological progress, buys time to replace fuel-inefficient capital equipment, allows time for learning, and may lead to some permanent sequestration as the new land use continues indefinitely (Marland, Fruit and Sedjo 2001).

[7] Even Herzog et al. (2003) admit that fossil fuels left in the ground may not be used at some future date if society commits to de-carbonize energy, while carbon in a terrestrial sink always has the potential to be released in the future. The bigger problem of not emitting CO_2 by burning fossil fuels pertains to leakages: Reduced fossil fuel use by some causes others to use more since prices are lower, while lower prices discourage new sources of energy.

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 reductions. 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. It is also possible to discount the number of offset credits 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).

Three 'practical' approaches to non-permanence of sinks have been discussed in the literature. One is to specify a conversion factor that translates years of temporary carbon storage into a permanent equivalent. The concept of ton-years has been proposed to make the conversion from temporary to permanent storage (Dutschke 2002; Herzog, Caldeira and Reilly 2003; IPCC 2000).

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.[8] The exchange rate ranges from 42 to 150 ton-years of temporary storage to cover one permanent ton.

Many observers have condemned the ton-year concept on various grounds. Herzog et al. (2003) argue that the value of storage is based on the arbitrary choice of an exchange rate, while Marland, Fruit and Sedjo (2001) point out that 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). That is, the ton-year concept could lead to double counting. Yet, the concept of ton-years has a certain appeal, primarily because it provides a simple, albeit somewhat naïve, accounting solution to the problem of permanence. The choice of an exchange rate, or, rather, timeframe, is political (which is another reason for its condemnation). Once an exchange rate is chosen, carbon uptake credits can be traded in a CO_2-emissions market in straightforward fashion. Yet, the ton-years approach has been rejected by most countries, primarily because it disadvantages carbon sinks relative to emissions avoidance (Dutschke 2002).

A second approach discussed extensively at Conferences of the Parties has been the potential creation of a 'temporary' certified emission reduction unit, denoted TCER. The idea is that a temporary carbon offset credit is purchased for a set period of time (e.g., one year or five years) expiring thereafter. Upon expiry, TCERs would have to be covered by substitute credits or reissued credits if the original project were continued.

[8] This interpretation is slightly different from the original intent. The original idea is to count a temporary ton as equivalent to a permanent one only if the carbon is sequestered for the full period of time given by the exchange rate. The advantage of the interpretation here is that it enables one to count carbon stored in a sink for periods as short as one year (as might be the case in agriculture).

Compared to ton-years, monitoring and verification are more onerous because a more complex system of bookkeeping will be required at the international level to keep track of credits. Countries favor this approach over other approaches because they can obtain carbon credits early, while delaying their 'payment' to a future date. Since politicians will discount future obligations very highly (essentially ignoring them), carbon offsets are treated as the equivalent of emission reductions.

A third approach to the problem of temporary versus permanent removal of CO_2 from the atmosphere is to employ a market device that would obviate the need for an arbitrary conversion factor or other forms of political maneuvering. Marland, Fruit and Sedjo (2001) and Sedjo and Marland (2003) 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 and the lease is renewed" (Marland, Fruit and Sedjo 2001). 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. The buyer-renter employs the limited-term benefits of the asset, but the seller-host retains long-term discretion over the asset (Sedjo and Marland 2003).

Rather than the authority establishing a conversion factor, the interaction between the market for emission reduction credits and that for carbon sink credits determines the conversion rate between permanent and temporary removals of CO_2 from the atmosphere. The rental rate for temporary storage is based on the price of a permanent energy emissions credit, which is determined in the domestic or international market. The annual rental rate (q) is simply the price of permanent emission credit (P) multiplied by the discount rate (r), which equals the established financial rate of interest (if carbon credits are to compete with other financial assets) adjusted for the risks inherent to carbon uptake (e.g., fire risk, slower than expected tree growth, etc.). Thus, $q = P \times r$, which is a well-known annuity formula. If emissions are trading for \$15 per t CO_2, say, and the risk-adjusted discount rate is 10%, then the annual rental for a t CO_2 in a terrestrial sink would be \$1.50 per t CO_2. This would be the selling price for biological carbon uptake, and, like the ton-year concept, it may make terrestrial sink projects less attractive than they might be under some other political solution.

A rental system works best if we are dealing with credit trading as opposed to allowance trading. Under a cap-and-trade scheme, it would be necessary to set not only a cap on emissions from fossil fuel consumption, but also a cap on sinks. In that case, one might expect separate markets to evolve for emissions and carbon sink allowances.

3. PROGNOSIS FOR FOREST ECOSYSTEM SINKS

Conservation of forest ecosystems that are threatened by deforestation, enhanced management of existing forests, reforestation of sites that have been denuded earlier, and afforestation are some ways in which carbon offset credits might be earned. The question is: Are carbon offsets created in these different ways competitive with emission reductions? If not, there is little sense in pursuing them, even though they might indeed increase the amount of carbon in forest ecosystems. As noted in section 1, the KP deals with forest (and agricultural) sinks in interesting ways in order to make them attractive as means for enabling countries to attain their KP targets. In theory, carbon flux in terrestrial ecosystems needs to take into account the carbon debit from harvesting trees, or otherwise changing land use (e.g., draining sloughs/swamps), 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).

Evidence from Canada, for example, indicates that, for the most part, 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). While many of Canada's forests regenerate naturally, only artificial regeneration that is not required by law as a normal part of forestry operations can truly result in carbon offset credits (although the KP currently permits some credits to count that are not additional). Artificial regeneration is costly and returns accrue in the distant future, making such investments unprofitable (van Kooten and Folmer 2004, p.395), even when the potential value of carbon offsets is taken into account. However, if short-rotation, hybrid poplar plantations replace natural forests, might forest management result in the creation of carbon offset credits that are competitive with emission reduction credits. 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).

To determine the cost effectiveness of various forest activities in creating carbon offset credits, van Kooten et al. (2004) investigated information from 55 studies. A meta-regression analysis of 981 estimates of the costs of creating carbon offsets using forestry yielded some interesting conclusions. Studies were classified into four different types of forestry projects – forest conservation programs that prevent harvesting of trees (and subsequent release of carbon), forest management programs that enhance tree growth, tree planting (afforestation) programs, and agroforestry projects where trees are planted in fields that continue to be used for crop production or grazing. Forest conservation was chosen as the baseline program.

Studies were also classified by three locations: tropics, North American Great Plains, and all other regions, which included mainly studies in the U.S. South, the U.S. cornbelt, the U.S. New England states, Europe and studies that covered more than one region (including global efforts at estimating costs of carbon uptake). The 'other' region was chosen as the baseline.

What factors appear to have an important effect on estimates of the cost of carbon uptake in forest ecosystems? (1) When the opportunity cost of land was taken into account (which was not done in all studies), carbon uptake costs were significantly higher. (2) If a study was peer reviewed, estimated costs were 10 to 30 times higher. (3) As expected, discounting of operating, monitoring and other annual costs lowered the overall estimate of sequestration costs. However, discounting of physical carbon did not appear to have a big effect. (4) Studies that included carbon product sinks had lower overall carbon sequestration costs, although inclusion of soil carbon pools did not have a statistically significant effect on costs. (5) Most studies computed only the average cost of carbon uptake; if marginal cost was calculated, it was much larger. (6) Tree planting and agroforestry activities increase costs by more than 200%. (7) Finally, costs in the Great Plains region were significantly lower than those in other regions of the world.

A summary of the costs of carbon uptake in forest ecosystems is provided in Table 1. Baseline estimates of costs of sequestering carbon through forest conservation are US$46.62–$260.29 per tC ($12.71–$70.99 per t CO_2).[9] 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 lowest – some $3.42–$18.67/t CO_2. Average costs are greater, $31.84–$383.62/t CO_2, when appropriate account is taken of the opportunity costs of land. Since the vast majority of studies ignored the ephemeral nature of carbon offsets and none the potential transaction (measuring, monitoring) costs, the costs reported in Table 1 are probably an underestimate of the true costs of creating carbon offset credits.

<Insert Table 1 about here>

4. PROGNOSIS FOR AGRICULTURAL SINKS

Much the same story can be told about agricultural soil-carbon sinks. In order to increase soil organic carbon, farmers need to change their agronomic practices. In drier regions where tillage summer fallow is used to conserve soil moisture, this requires the use of chemical fallow or continuous cropping, or cessation of cropping altogether (i.e., return to grassland). In other agricultural regions, a movement from conventional tillage (CT) to reduced tillage (RT) or no tillage (NT) might increase soil organic carbon. Soil

[9] In Table 1, costs are provided on a per tC basis. They can be converted to a per t CO_2 basis by multiplying by 12/44. Conversely, if emissions trade at $15 per t CO_2, then carbon offset credits must trade for $55 per tC or less to be competitive.

carbon increases by increasing plant biomass entering the soil and/or reducing rates of decay of organic matter. This might be done by switching to RT or NT, or replacing tillage summer fallow by continuous cropping or chemical summer fallow. Are such practices worth pursuing, and can they result in significant changes in carbon flux?

Undoubtedly, there are soil erosion benefits from practicing reduced (conservation) tillage and zero tillage. In many cases, lower costs because of fewer field operations offset higher chemical costs since prices of herbicides have fallen in recent years (although there may be higher social costs associated with the environmental spillovers from higher chemical use). As a result the private benefits, the extent of RT and NT has increased significantly in the United States in the past several decades. In 1997 in the United States, farmers employed conventional tillage on 36.5% of 294.7 million acres (119.3 million ha) planted to cropland; 26.2% was planted using reduced tillage and 15.6% using zero tillage, with other crop residue methods employed on the remaining land (Padgitt et al. 2000, p.67). Not included were some 20 million acres of land left in tillage summer fallow in drier regions: 22% of all wheat planted in the U.S. in 1997 was part of a wheat-fallow rotation and, in some states, three-quarters of all wheat was part of a wheat-fallow rotation.

West and Marland (2001) use U.S. data on carbon uptake in soils, production of biomass, chemical and fuel use, machinery requirements and so on to compare CT, RT and NT in terms of their carbon flux. They provide a detailed carbon accounting for each practice, concluding that, due primarily to extra chemical use, RT does not differ significantly from CT in terms of carbon uptake benefits, but that NT results in an average relative net carbon flux of –368 kg C per ha per year, with –337 kg C ha^{-1} yr^{-1}

due to carbon sequestration in soil, –46 kg C ha^{-1} yr^{-1} due to a reduction in machinery operations and +15 kg C ha^{-1} yr^{-1} due to higher carbon emissions from an increase in the use of agricultural inputs. While annual savings in carbon emissions of 31 kg C ha^{-1} yr^{-1} last indefinitely, accumulation of carbon in soil reaches equilibrium after 40 years. West and Marland (2001) assume that the *rate* of uptake in soil is constant at 337 kg C ha^{-1} yr^{-1} for the first 20 years and then declines linearly over the next 20 years. However, as noted earlier, stored carbon can be released back into the atmosphere in as little as a year when CT is resumed.

Their estimates of carbon uptake by soils in the prairie region of Canada as a result of going from CT to NT vary from 100 to 500 kg C ha^{-1} yr^{-1} (West and Marland 2001). Using these results and discount rates of 2% and 4%, van Kooten (2004) estimates that the net discounted carbon prevented from entering the atmosphere as a result of a shift to NT from CT varies from about 4 tC per ha to at most 12.5 tC per ha. Compared to forest plantations, the amount of carbon that can potentially be prevented from entering the atmosphere by changing to zero tillage is small.

Research by Manley et al. (2004) comes to a more pessimistic conclusion even than West and Marland. They find that the costs per tonne of carbon in going from CT to NT are enormous, and may even be infinite in some cases because there may be very little or no addition to SOC, particularly in North America’s grain belt. Manley et al. conduct two meta-regression analyses to investigate the potential for the switch from conventional to zero tillage to create carbon offset credits that would be competitive with emission reductions. The first meta-analysis consisted of 51 studies and 374 separate observations comparing carbon accumulation under CT and NT. A particularly important finding was that no-till cultivation may store no carbon at all if measurements are taken at sufficient depth. That is, the depth to which researchers measured SOC was important in determining whether there were carbon-sink gains from no-till agriculture. In some regions, including the Great Plains of North America, the carbon-uptake benefits of NT are non-existent. A possible explanation is that, under conventional tillage, crop residue is plowed under and carbon gets stored at the bottom of the plow layer; with no-till, some carbon enters the upper layer of the soil pool, but as much CO_2 is lost from decaying residue as is lost from plowing under conventional tillage.

In a second meta-regression analysis, Manley et al. examined 52 studies and 536 separate observations of the costs of switching from conventional tillage to no-till. Costs per ton of carbon uptake were determined by combining the two results (see Table 2). The viability of agricultural carbon sinks was found to vary by region and crop, with no-till representing a low-cost option in some regions (costs of just over \$10/tC or about \$3 per t CO_2), but a high-cost option in others (costs of \$100-\$400/tC). Nonetheless, in some limited circumstances no-till cultivation may yield a 'triple dividend' of carbon storage, increased returns and reduced soil erosion, but in most cases creating carbon offset credits in agricultural soils is not cost effective because reduced tillage practices store little or no carbon.

<Insert Table 2 about here>

Where continuous wheat, reduced (conservation) tillage and/or zero tillage are already in use, it is difficult to make the case that carbon offset credits are being created –

the 'additionality' condition is violated. However, if landowners practicing conventional tillage can claim carbon offset credits by making a switch to RT or NT (or to continuous cropping or use of chemical fallow), it will be necessary to extend the claim to extant practitioners of RT, NT and reduced tillage summer fallow to prevent them from switching back to conventional practices to become eligible claimants in the future (see Lewandrowski et al. 2004, p.11).

There is a further problem. The advantages of conservation and zero tillage are financial in the sense that there are fewer machinery operations. This cost offsets the cost of increased chemical use and the value of reduced crop yields (which might be small). As more land is put into RT or NT or converted to forestry, and demand for 'energy' crops (to produce ethanol, say) increases, crop prices will rise. This will result in a greater loss in revenue from reduced crop yields, making RT and NT less attractive.

5. FINAL REMARKS

Although the Kyoto Process enables countries to rely on carbon sinks in a major way for meeting their agreed-upon greenhouse gas emission reduction targets, the introduction of carbon uptake in lieu of emissions reduction constitutes a distraction from the real business of addressing anthropogenic causes of climate change. While many argue that terrestrial carbon sinks can serve an important role in the transition to a de-carbonized energy regime, the politics surrounding the creation, verification and counting of carbon offsets credits under the KP have made this policy instrument much too unreliable to be taken seriously in combating climate change. Parties attempt to gain credits for activities that cannot be considered additional, but are part of business-as-usual practices, such as the spreading adoption of conservation tillage, planting of shelterbelts, and silviculture practices that are required by law or participation in a forest certification scheme. The measurement, monitoring and enforcement related to the creation of carbon offset credits is problematic and could result in large transaction costs.

Leakages are often ignored in the calculation of carbon credits, even though leakages lead to a reduction in the total carbon uptake attributed to a project by fifty percent or more. Leakages are ignored because they are difficult to measure. In practice, this issue is resolved by limiting the parameters of a project, say the geographic extent of what is to be included, or assuming the project is too small to have an impact on other regions (even when the claimed amount of carbon is large).

Nonetheless, evidence indicates that, even when leakages and transaction costs are ignored, the costs of carbon uptake in forest and, particularly, agricultural sinks are large compared to the costs of emissions reduction. Based on meta-regression analyses, if one considers only the average (let alone marginal) costs of carbon uptake in forest sinks and uses a cutoff of \$55 per tC (\$15 per t CO_2) for projects to be competitive with emission reductions, there are no forest activities in any region that meet this threshold if one considers only peer reviewed studies (see Table 1). Likewise, even abstracting from the issue of the depth to which soil carbon is measured, results from meta analyses suggest that only changes in agronomic practices in the U.S. South can sequester enough carbon to make a switch from conventional till to no till a ‘project’ that is competitive with emission reductions (Table 2). Further, the estimates in Tables 1 and 2 are an underestimate of the true costs of carbon uptake because the studies generally fail to address the temporary nature of carbon sinks.

While the KP permits countries to claim carbon credits associated with questionable sink activities, countries have been less than helpful in attempting to alleviate concerns that the inclusion of sinks in the KP is nothing more than smoke and mirrors. They have opposed any efforts that address the ephemeral nature of sinks in ways that lead to carbon offsets having lower value than emission reductions. Yet, the KP has also failed to treat carbon sinks in a fair and equitable manner. Post-harvest sequestration of carbon in products does not result in carbon credits, even though studies indicate that product sinks play an important role in keeping CO_2 out of the atmosphere. If credit for product sinks is allowed, the value of wood construction will be enhanced thereby reducing reliance on cement, whose production releases large quantities of greenhouse gases.

Finally, recent technological developments in the efficiency of using biomass to produce energy have emerged. These include field-level processes for producing bio-oils from wood fiber and more efficient burners for generating electricity from biomass. This is particularly important in regions where removal of fuel loads is needed to control wildfire, removal of trees damaged by pests such as the mountain pine beetle is warranted, and gathering of crop residues to be burned for electricity is possible. The economics of many of these options as well as other promising means for using biomass to reduce the atmospheric concentration of CO_2 need to be investigated. It will be the inclusion of these activities in the carbon accounting framework that can make biological sinks an attractive option for mitigating climate change.

Table 1: Predicted Average and Marginal Costs of Creating Carbon Offsets through Forestry Activities, US$ 2003 per tC, Various Scenarios[a]

Scenario	Average costs (if studies not reviewed)	Average costs (based on peer reviewed studies)	Marginal costs (based on peer reviewed studies)
Baseline (Other regions with Forest Conservation)	8.45	217.01	15,700.48
Other regions			
Planting	24.80	637.10	46,094.38
Agroforestry	26.65	684.67	49,535.57
Forest Management	8.09	207.87	15,039.67
Other regions with conservation			
Soil Sink	5.35	137.54	9,951.18
Fuel Substitution	4.45	114.31	8,270.47
Product Sink	2.25	57.74	4,177.41
Opportunity Cost of Land	46.20	1186.70	85,857.68
Tropics			
Conservation	10.01	257.22	18,609.85
Planting	29.40	755.16	54,635.89
Agroforestry	31.59	811.54	58,714.75
Forest Management	9.59	246.39	17,826.59
Tropics with conservation			
Soil Sink	6.35	163.03	11,795.18
Fuel Substitution	5.27	135.49	9,803.03
Product Sink	2.66	68.44	4,951.50
Opportunity Cost of Land	54.76	1406.60	101,767.52
Great Plains			
Conservation	5.36	137.68	9,961.14
Planting	15.74	404.21	29,244.49
Agroforestry	16.91	434.38	31,427.74
Forest Management	5.13	131.89	9,541.88
Great Plains with conservation			
Soil Sink	3.40	87.26	6,313.51
Fuel Substitution	2.82	72.52	5,247.18
Product Sink	1.43	36.63	2,650.35
Opportunity Cost of Land	29.31	752.90	54,472.23

[a] Average costs and marginal costs are determined from the respective regressions provided in van Kooten et al. (2004). If the study was peer reviewed, the dummy variable in the regression is set to 1; otherwise it is 0.

Source: Calculated from information provided in van Kooten et al. (2004)

Table 2: Net Costs of Carbon Sequestered in Going from CT to NT ($US2003 per tC)

		At Measured Depth of Soil	
Region	Crop	Shallow	Deep
South	Wheat	$10.45	$13.10
	Other crop	$2.02	$2.04
Prairies	Wheat	$390.75	∞
	Other crop	$153.09	$215.82
Corn Belt	Wheat	$147.55	$193.48
	Other crop	$87.31	$89.73

Source: Manley et al. (2004). Converted from $US2001 to $US2003 using the US CPI.

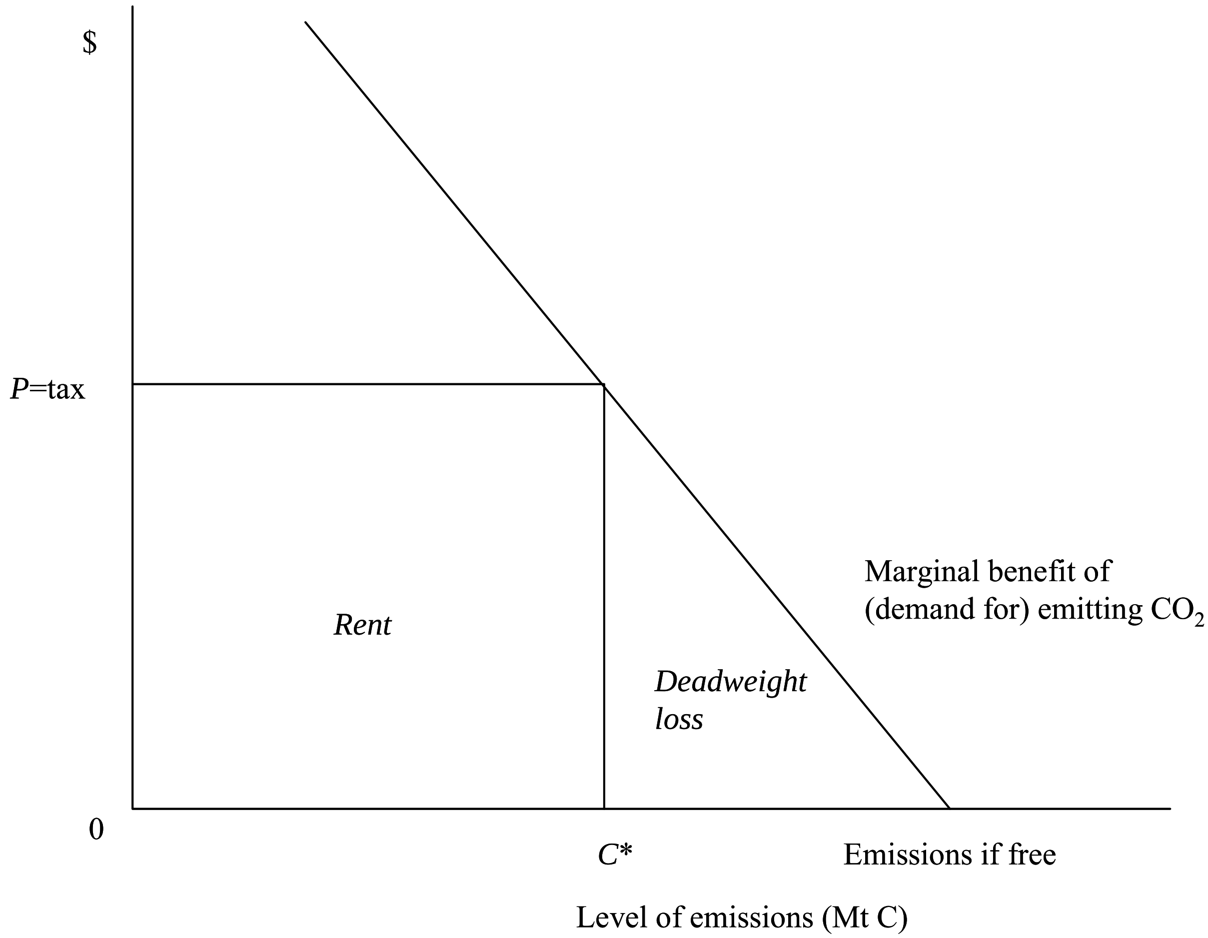

Figure 1: Controlling CO_2 emissions using economic incentives

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