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Carbon Credits for Forests and Forest Products *

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Abstract
It is possible to make a current valuation of the effects of carbon dioxide which tracks a valuation done under the metric of expected present value and also tracks realized values. The implementation of a carbon credit scheme based on green accounting could go as follows:

1. At dates strictly between planned harvests, impute a credit of the value of carbon fixing through forest growth; it is possible to subtract from that credit a premium corresponding to an insurance against fire.

2. At dates when a fire occurs, do not make any debit if an insurance has been charged; otherwise impose a debit corresponding to the carbon value of the forest lost through fire.

3. At all dates, for each past harvest, impute a debit for the value of the current decay of forest products.

4. At the time of harvest, impute a discrete debit for the value of waste.

key words: Carbon credit; Forest; Green accounting; Afforestation; Deforestation; Wood products.
J.E.L. classification: H00, Q280, Q290, Q380, Q390.

Résumé
L'évaluation des effets de verrouillage du gaz carbonique par la forêt et les produits forestiers fait intervenir des espérances mathématiques de valeurs futures. Pourtant nous montrons qu'on peut en faire la mesure à partir de valeurs courantes, ce qui suggère le système suivant d'attribution de crédits carbone.

1. Entre les dates des coupes, imputer un crédit correspondant à la valeur du carbone immobilisé par la croissance des arbres; éventuellement en soustraire un montant correspondant à une assurance contre les incendies.

2. Lorsque se produit un incendie, n'imputer aucun débit si la prime d'assurance a été déduite en #1; sinon déduire la valeur carbone de la forêt brûlée..

3. En toute date déduire la valeur des produits forestiers anciens dont le carbone est restitué à l'atmosphère.

4. Au moment des coupes imputer un débit correspondant aux déchets.

mots-clés: Crédits carbone; Forêt; Comptabilité verte; Afforestation; Déforestation; Produits forestiers.
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1. Introduction

Considerable quantities of carbon are contained in the world's forests. As trees grow, they absorb or fix a quantity of carbon which is proportional to the growth of their biomass. This observation has led many to observe that increasing the area devoted to forests, or the stock of timber in existing forests, could be a method to mitigate the increase of atmospheric carbon dioxide (CO2), a greenhouse gas.

According to the IPCC (Intergovernmental Panel on Climate Change, 2000), terrestrial ecosystems may have served as a small net sink for CO2 over the last two decades, to the tune of about 200 to 700 (metric) tonnes per year (Mty^{-1}) of carbon (C). This flow is small when compared with yearly emissions from fossil fuel consumption of more than 6 000 Mty^{-1} during the 1990's. There is considerable debate about the potential of afforestation and reforestation or of improved forestry practices for mitigating climate change. Indeed, the IPCC has attempted to quantify the potential of improved forest management and agroforestry on existing forests, plus the potential of changing land-use to agroforestry. It estimates that it is unlikely that the increase in the yearly contribution from forests in 2010 could exceed 586 Mty^{-1}, less than 10% of current emissions from fossil fuels (IPCC, 2000, Tables 2 and 4). The committment made in Kyoto, however, is for a reduction of total emissions to 96% of the 1990 level, not for their elimination. Achieving only half of the potential identified by the IPCC would go a long way toward meeting the Kyoto committment.

This is especially true for countries which may rely on forests to meet a portion of their commitments. For example, for Canada, which accounts for 10% of the earth's forest area and 2.3% of global emissions, the potential contribution of forest and forest products to meeting the Kyoto committment is very significant. The total store of carbon in forest and related resources (including soil and forest products) was over 225 billion tonnes in the 1990's (Canadian Forest Service, 1999). Of this, very roughly, perhaps 25% is vegetation and may be amenable to human manipulation. The Kyoto committment of Canada is estimated to imply a reduction of 50 Mty^{-1} in C emissions in

2010. In 1990, slash left on forest sites upon harvest to be burnt or allowed to decompose amounted to 16 Mt C. An improvement of 30% in that very particular component of forestry practice would contribute 10% of the Canadian commitment. Quite possibly, if it took full advantage of all major possible emission reduction possibilities linked with the forest and forest products, Canada could find it profitable to participate in meeting part of other countries' commitments.

Whatever the potential contribution of forests and forest products to the reduction in CO2 emissions, it will fail to materialize unless actions to realize it are either imposed or properly rewarded. In this paper, we explore the underlying economic principles that apply to this problem, and we discuss how carbon credits could be attributed in accord with such principles. We also compare these principles with the practical carbon accounting practices of the IPCC and the UN Food and Agricultural Organization discussed in Winjum et al. (1998).

Any country which increases its forest base, improves its forestry practice, or modifies its forest products mix should receive carbon credits under the Kyoto Protocol on global warming. A simple way to accord such credits could be to observe the net growth of biomass in the country and to credit the current value of carbon fixing to that growth. This value, $q(t)$ at some time t, could be determined in various ways depending on policies adopted, such as by fiat, by the value of tradeable carbon permits, or by the unit carbon tax on emissions of carbon. If df/dt is the growth of biomass, then the credit for biomass changes could be $q(t)df/dt$.

A complicating factor is that biomass takes the form of standing trees, but also survives in the form of wood products. To the extent that it is not practical to trace the decay of wood products, it may be desirable to take this phenomenon into account in a forward looking fashion, perhaps, as we are going to suggest, at the production or harvesting stage.

Also, even if the intent is to leave the land as forest forever, forests do not continue to grow forever, but are cut and replanted or else reach a stable state. Pearce (1994) incorporates such considerations into a cost-benefit analysis of afforestation in Scotland.

In general, establishing a permanent forest consists, not simply of letting the forest grow at a particular point in time, but of devoting land to this particular use over an indefinite future. As the forest grows, there is a continuing risk of destruction by fire or pests. If the forest is expected to be cut at maturity then, as time passes, not only does the forest grow but the eventual harvest of the forest is closer. Thus, the capacity of the forest land to provide further carbon fixing is affected even as the carbon is fixed.

Since the value of the forest to humanity as a sink for carbon is a capital value rather than simply a flow, an internally consistent system of carbon credits would recognize effects on the future ability to absorb carbon as well as the current effect of the growth of trees. Consequently, the credit system is an exercise in green accounting, the attempt to recognize the values of environmental resources as economic assets. In the literature on green accounting, there is a tension between measuring the changes in value through green net national product (NNP) and through the changes in social wealth. Theoretically, the first is simply interest on the second. But it is widely recognized that obtaining the (present) value of wealth at any time is more difficult than obtaining the NNP, a current measure.

In this paper, we characterize the measure of wealth in terms of the ability of a parcel of land to fix carbon. This means the carbon remaining locked into wood products from previous rotations; the carbon being currently fixed; and the contributions from future rotations. Our analysis points up some subtle issues that must be taken into account in a system of credits for forest growth, and initially we obtain a difficult expression for the credits that should be accorded. Fortunately, it turns out that there exists an equivalent system of credits and debits which rely only on current magnitudes. Such a system simplifies the conceptualization as well as the accounting of carbon credits, while allowing a clear identification of its risk sharing and incentive effects.

2. The Value of Fixing Carbon: preliminary remarks

The present paper uses the literature on forestry as a background, but departs from it in an important way. In that literature, one important consideration is the determination of the optimal harvest rotation, using Faustmann's formula or generalizations of it. Depending on the considerations the analyst wishes to introduce, the generalizations can be complicated. Indeed, the introduction of carbon credits could influence the rotation period (Ariste and Lasserre, 2000), and even the choice of species of trees to be grown (cf. Pearce 1994: table 17.6). Moreover, we have already observed that the value of fixing a unit of carbon at time t, $q(t)$, can vary. This value is expected to rise as the concentration of carbon in the atmosphere increases. As a result of the price changes, the optimal rotation period may vary from rotation to rotation. In our model, we do not determine a set of rotation periods, but simply presume that such a set has been determined, somehow, be it in an optimal way or not. Also, for simplicity we assume that the period of a future rotation is not affected by the timing of its start, as influenced by fires up to the beginning of that rotation. It will be intuitively clear that assuming otherwise would make our derivations more complicated but not affect our conclusions. As there is uncertainty respecting forest fires or pestilence, all of our computations should be understood to be in terms of expected values.

We consider that any forest begins with afforestation at a time t_1 which we normalize to zero. Let the time at which the nth rotation begins be t_n, and the harvesting age for this rotation be T_n. Let us consider a point in time t during the nth rotation, $n \geq 1$. If $n = 1$ and $t = t_1 = 0$, we are studying afforestation in the sense of the IPCC, that is 'the establishment of forest on land that has been without forest for a period of time (e.g., 20-50 years or more) and was previously under a different land use.' (IPCC, 2000, p. 6). If $n > 1$ and $t = t_n$, the current action is what the IPCC (*idem,* p. 6) defines as reforestation, 'the activity of regenerating trees immediately after disturbance or harvesting'. If the forest is old growth or has been set aside as wilderness, we shall say that $n = 1$ and $T_n = \infty$.

In any case, the newly established rotation can end with a forest fire at some time $t < t_n + T_n$ or by harvesting at time $t_n + T_n$. There is a probability, ρ (which we assume to be constant), of a fire at any instant $t < t_n + T_n$. Hence, the probability of the nth rotation's surviving to time t is $e^{-\rho(t-t_n)}$. The probability of a fire on the interval $(t, t + dt)$ is, then, $\rho e^{-\rho(t-t_n)}dt$.

Let the quantity of carbon fixed in the biomass of the forest (an even-aged stand) at time t be $f(t - t_n)$; then the rate of growth is $df(t - t_n)/dt = \dot{f}(t - t_n)$. This rate of growth is net of the (expected) damages of pests. If the forest survives to age T_n, it is cut. A fraction λ_n is useful and $(1 - \lambda_n)$ is waste, immediately being transformed into carbon dioxide (say by burning or rapid decay); this ratio is determined by the choice of inputs (recovery effort) as well as by the production mix (e.g. the proportion of construction products relative to paper in output). The part which is useful is transformed into a mix of wood products, the proportion of each product i being Γ_{ni}, and its rate of decay γ_{ni} (assumed to be constant).

The proportions λ_n, Γ_{ni} and γ_{ni} are important elements of the carbon accounting system. They are endogenously determined in the same way as the rotations are. In a market economy, they respond to wood product and input prices, as well as the carbon credit, if any. If the value of the carbon credit is increased, one may expect λ_n to increase and production to be reallocated toward slow-release forest products. For the purpose of green accounting, however, one does not need to analyze how these variables are determined; they just need to be measured. In what follows, in order to keep the notation simpler, we assume that output is one-dimensional: $\Gamma_{ni} = \Gamma = 1$ and $\gamma_{ni} = \gamma_n$.

3. Evaluating the current rotation

All our computations will be in terms of expected values at time t, with the expectations operator suppressed to minimize clutter. The value of carbon already in the forest is $q(t) f(t)$. To time t, however, we assume that this quantity has already been allocated carbon credits in the past, and that credits for carbon are forward-looking. The expected (at time t) total future contribution of rotation n to carbon fixing is, in value terms,

$$\begin{aligned} V_t^n &= \int_t^{t_n+T_n} e^{-(r+\rho)(s-t)} q(s) \left[\dot{f}(s) - \rho f(s)\right] ds \\ &\quad -e^{-(r+\rho)(t_n+T_n-t)} f(T_n) \left[(1-\lambda_n) q(t_n+T_n)\right] \\ &\quad -e^{-(r+\rho)(t_n+T_n-t)} f(T_n) \left[\lambda_n \int_{t_n+T_n}^{\infty} \gamma_n e^{-(r+\gamma_n)(s-t_n-T_n)} q(s)\, ds\right]. \end{aligned}$$

The first term is the present discounted value of the growth of the forest less the probability of a fire at time s times the quantity of greenhouse gas released in the event of burning. The net expected growth is discounted for interest and for the probability of survival to time s. The second and third terms represent the expected present value of future releases of carbon dioxide from harvested biomass: a fraction $1-\lambda_n$ is released immediately at harvest time; the rest is released in perpetuity at rate γ_n.

4. Evaluating past and future rotations

At time t during the nth rotation, there is also a component of total value from the mth rotation of this forest, $m < n$. (Recall that $t_1 = 0$; the rotations begin at the time of afforestation.) This component is negative because it is the value of the decay of what remains of the mth rotation (if it survived to maturity),

$$V_t^m = -\lambda_m f(T_m) \int_t^{\infty} \gamma_m q(s) e^{-r(s-t)} e^{-\gamma_m(s-t_m-T_m)}\, ds.$$

Let $\delta_m = 1$ if the mth rotation survived to maturity, and be zero otherwise. Then the total contribution of harvested rotations is

$$\begin{aligned} V_t^{n-} &= \sum_{m=1}^{n-1} \delta_m V_t^m \\ &= -\sum_{m=1}^{n-1} \delta_m \lambda_m f(T_m) \int_t^{\infty} \gamma_m q(s) e^{-r(s-t)} e^{-\gamma_m(s-t_m-T_m)}\, ds. \end{aligned}$$

Finally, at time t during the nth rotation, there are expected contributions by future rotations to value. The mth rotation, $m > n$, begins at a time which is uncertain, because of the possibilities of fires in rotations n through $m-1$. The time at which it is planted, then, is stochastic. But the stationarity of our problem allows this randomness to be expressed in terms of the randomness of the beginning of rotation $n+1$, in the following way. First, let the expected benefit from the sequence of all future rotations $m \geq n+1$, which begins at time t_{n+1}, be W_{n+1}. At time t the starting date of rotation $n+1$ is uncertain. We know that the following holds:

$$\Pr\left(t_{n+1} = T_n + t_n\right) = \exp\left[-\rho\left(T_n + t_n - t\right)\right],$$

and, for $\tau \in (0, T_n + t_n - t)$,

$$\Pr\left[t_{n+1} \in (t+\tau, t+\tau+d\tau)\right] = \rho \exp\left(-\rho\tau\right) d\tau.$$

Therefore, the total expected contribution of all future rotations at time t is

$$\begin{aligned} V_t^{n+} &= W_{n+1}\left\{\exp\left[-\left(r+\rho\right)\left(T_n + t_n - t\right)\right] + \int_0^{T_n+t_n-t} e^{-r\tau}\rho e^{-\rho\tau}\, d\tau\right\} \\ &= W_{n+1}\left\{\frac{\rho}{\rho+r} + \frac{r}{\rho+r}\exp\left[-\left(r+\rho\right)\left(T_n + t_n - t\right)\right]\right\}. \end{aligned}$$

The total value of the expected contribution at t of maintaining this parcel of land in forest use in perpetuity is

$$V_t = V_t^{n-} + V_t^{n} + V_t^{n+}.$$

This value is a capitalized value of all future components of changes of carbon as a result of the project.

5. The return on the parcel of land

The cost of capital, which must be returned by the project, consists of the return on the capital value plus the depreciation. The return on the asset value is included because the carbon in the atmosphere is a stock which produces a flow of costs to society in each time period. Reducing the stock by sequestering it in forest biomass, then, provides a flow of benefits (negative costs). These benefits are the return which society seeks in building up the stock of biomass. Depreciation is the negative of the rate of change of the value V_t; it is positive if the value decreases. Both of these values depend on the realizations of carbon savings over an uncertain future.

Determining the return on the capital value is a subtle task. Consider the time derivative of V_t^{n-}:

$$\dot{V}_t^{n-} = rV_t^{n-} + \sum_{m=1}^{n-1} \delta_m \lambda_m f\left(T_m\right) \gamma_m q(t) e^{-\gamma_m (t-t_m-T_m)}. \tag{1}$$

The rate of change is the interest on the value (which is negative) of previous rotations at time t, plus a second term representing the current contribution. The first term appears because, as time passes, any future event (here, the realization of the decay at future dates) is sooner and is discounted less. We have assumed that the effects of previous rotations is certain, and so the appropriate interest rate is r.

For current rotations,

$$\dot{V}_t^{n} = \left(r+\rho\right) V_t^{n} - q\left(t\right) \left[\dot{f}\left(t-t_n\right) - \rho f\left(t-t_n\right)\right]. \tag{2}$$

As is common in problems with a Poisson hazard (with hazard rate ρ), the effective interest rate is $r+\rho$, not r, because of the possibility of destruction of the forest by fire.

For future rotations, by direct differentiation and substitutions from the equation for

V_t^{n+},

$$\begin{aligned}\dot{V}_t^{n+} &= rW_{n+1}\exp\left[-\left(\rho+r\right)\left(T_n+t_n-t\right)\right] \\ &= \left[\left(\rho+r\right)V_t^{n+}-\rho W_{n+1}\right] \\ &= r\left(\frac{r+\rho}{r+\rho\exp\left[\left(r+\rho\right)\left(T_n+t_n-t\right)\right]}\right)V_t^{n+}. \end{aligned} \tag{3}$$

The effective interest rate for future rotations varies with the point in the rotation period.

The equations for $\dot{V}_t^{n-}$, $\dot{V}_t^{n}$ and V_t^{n+} are examples of the fundamental asset-market-equilibrium equation, which equates the total return on an asset to the sum of a dividend and a capital gain. Society invests in the forest in such a way as to be compensated for the opportunity cost of the funds invested, and the compensation must take into account the possibility of destruction of the current and future rotations by fire. As noted above, the compensation is for the return on and the depreciation of the asset value.

The change in value, for $t \in (t_n, t_n + T_n)$, is

$$\dot{V}_t = \dot{V}_t^{n-} + \dot{V}_t^{n} + \dot{V}_t^{n+}.$$

If $\dot{V}_t$ is positive, there is an appreciation of value, and if $\dot{V}_t$ is negative, there is a depreciation.

The upshot is that, at times strictly between planned harvests, we can express the credit for sequestration C_t in terms of the asset values of the forest: the net contribution of the forest to society, and hence its credit, at time t, is the sum of the return on the asset value and the depreciation,

$$C_t = rV_t^{n-} + \left(r+\rho\right)V_t^{n} + r\frac{r+\rho}{r+\rho\exp\left[\left(r+\rho\right)\left(T_n+t_n-t\right)\right]}V_t^{n+} - \dot{V}_t. \tag{4}$$

As has been pointed out by scholars studying the green accounts (e.g. Aronsson and Löfgren 1998), calculating the value of the investment, V_t, in carbon fixing in order to obtain C_t would be a formidable task: It would require imputations of values far into the future. But the exercise does point up that the problem of correctly accounting for the forest involves much more than simply crediting a country for the rate of growth of its forests. Any loss of forest value, such as through forest fires or pests, should be considered a debit to be made up otherwise. The decay of wooden or paper products already made should be a debit as well. For example, wood chips strewn on park paths eventually decay, as does old wooden furniture placed in a garbage dump. It is not enough simply to keep track of the quantity of biomass in the forest itself.

6. A Current Measure

Fortunately, there is a way to express the credit proposed in equation (4) in a way which involves only current flows of value, and not the imputation and capitalization of future flows over an uncertain future represented by V_t^{n-}, V_t^n, V_t^{n+} and their rates of change. Rearranging equation (4) using equations (1), (2) and (3) yields, for $t \in (t_n, t_n + T_n)$ (for times strictly between planned harvests),

$$C_t = q(t) \left\{ \left[\dot{f}(t - t_n) - \rho f(t - t_n) \right] - \sum_{m=1}^{n-1} \delta_m \lambda_m f(T_m) \gamma_m e^{-\gamma_m (t - t_m - T_m)} \right\}.$$

The credit involves only physical changes occuring at the current instant, all evaluated at the current price $q(t)$, as determined by the current price of carbon permits, for example.

At harvest times, when $t = t_n + T_n$, there is a discrete jump in the value V_t^n because the fraction $(1 - \lambda_n)$ of the harvest is wasted immediately, and so the change in value is minus $(1 - \lambda_n) f(T_n) q(t_n + T_n)$. In case of a fire occuring at s, $t_n < s < t_n + T_n$, there is also a discrete jump in V_t^n; however the formula remains valid, with appropriate changes in n and t_n: a new rotation starts right after the fire, so that n is incremented to $n + 1$; and the beginning of the new rotation is set at $t_{n+1} = s$. Thus the credit C_t experiences a discrete jump at s, but the formula to apply is unchanged.

This method of evaluation suggests the following policy for distribution of carbon credits, to nations and through them to local decision-making units:

CARBON CREDIT IMPLEMENTATION SCHEME

1. At dates t strictly between planned harvests, when the age of the stand is $\tau = t - t_n$, impute a credit of the value of carbon fixing through forest growth, $q(t)\dot{f}(\tau)$. *An additional deduction of $\rho f(\tau)$ may also be subtracted (see #2 and the discussion below). This deduction may be interpreted as an insurance premium against fire, and justifies that no carbon debit be imputed in case of fire.*

2. At dates t when a fire occurs, impose a debit of $q(t) f(\tau)$. *If a deduction has been subtracted from the credit for growth at step #1, do not make this debit.*

3. At all dates, for each past harvest $m < n$ impute a debit for the value of the current decay of forest products, $f(T_m)\lambda_m \gamma_m q(t) e^{-\gamma_m (t - t_m - T_m)}$.

4. Make no imputation for future harvests, $m > n$. Future harvests are not evaluated until they are actually planted.

5. At the time of harvest, impute a discrete debit for the value of waste, $(1 - \lambda_n) f(T_n) q(t_n + T_n)$.

7. Discussion and conclusion

The above implementation scheme is based on sound green accounting principles. A number of important issues remain to be discussed. First, how does it compare with existing carbon accounting systems? Second, what are the informational requirements for implementation? Finally, what are the incentive effects of introducing such a system and what precautions do they suggest?

There is a parallel literature on carbon accounting. Carbon accounting is widely used by scientists in various disciplines, and is a standard tool for the IPCC. As far as forests and wood products are concerned, Winjum *et al.* (1998) identify two main methodologies, *atmospheric flow* and *stock change*. Except for the focus on physical units instead of values, stock change evokes formula (4), giving the change in the carbon value of a parcel, while atmospheric flow corresponds to our current measure.

Let us focus on the atmospheric-flow method summarized in Figure 1 of their paper. Step 1 (roundwood harvest) corresponds to the measurement of $f(T_n)$, the current harvest, which involves a conversion from volume units in which harvest data are usually expressed into carbon content. Step 2 (slash) corresponds to establishing λ_n, where waste must include waste upon harvest and at the production stage. Step 3 (commodity) corresponds to establishing the breakdown of production into various products. As we mentioned earlier, γ_n is in fact a vector, each wood product having in theory its own decay rate. Winjum *et al.* distinguish two types of products, products whose life exceeds five years and other products; other studies have used finer breakdowns (Obersteiner, 1999). In fact, decay rates and product breakdown are used in step 4 (inherited), which corresponds to item #3 in our scheme.

PLEASE INSERT FIGURE 1 HERE

Not surprisingly, our brief review indicates that there is a clear correspondance between our sheme and standard carbon accounting methods; the required data are basically the same. However, with respect to the treatment of current growth between harvest dates, standard carbon accounting methods would not impose a deduction $\rho f(\tau)$ for fire risk, but impose a debit $f(\tau)$ at the time t when a fire occured. From a green accounting point of view, our formula accounts for the fact that, due to fire hazard, one ton of carbon in the atmosphere is not fully offset by one ton of carbon locked into wood. However, if we consider the practical side, it is more difficult to obtain data on ρ than it is to obtain data on fire: estimating ρ from fire data would require regional time series on the incidence of fires, while simply deducting losses from fires requires only current data.[1]

[1]This is especially true in view of the fact that, contrary to our assumption, the probability ρ is unlikely to be constant. It may depend on global warming, and hence on the success of efforts to reduce global warming.

This suggests simply imposing debits when fires (and weather or pest related damages) occur. Realized values may differ from expected ones. But, given that the social costs depend on realized values of carbon emissions, this divergence from expected values is desirable. Besides being less demanding in information and directly tracking realized social costs, that treatment would also provide sound incentives. Forest decision makers would privately benefit from their attempts to reduce fire or infestation hazards. Certainly, discrete, random charges could imply sudden needs to go into the market for permits, and hence hardships for a particular society at particular times. However, this society might be able to self-insure if the land area to be devoted to forest is large. If fires on the planet are not correlated, insurance markets may develop and even small countries also would have a greater incentive to maintain forests.

Applying our scheme at the harvesting/production stage would also provide sound incentives toward choosing the right product mix. Although the prices of wood products do not appear in our scheme, and although there is no provision for, say, subsidies favoring long-lived wood products over short-lived ones, forward looking producers, if they expected high future values of q, would have an incentive to adopt a product mix favoring slowly decaying products (low γ) in order to reduce future debits associated with wood products decay (item #3). Clearly, such a beneficial effect would not occur unless the payments associated with item #3 were truly linked with producers' own product mix, e.g. through prices faced by consumers. (By the same type of argument, incentives toward recycling or avoiding consumer waste would have to be handled using additional instruments.) Incentives would be appropriate for choices of future rotation periods $T_m, m \geq n$,[2] forestry practices, waste rates λ_n, etc.

The discussion stresses that any investment in forests as a carbon sink will not continue to provide large net credits. Eventually the fixing of carbon will reach a steady state and credits will pinch out. However, the observation that benefits eventually

[2]Analytically, maximizing the value of fixing carbon in a forest is similar to maximizing commercial values of timber or pulp, as summarized by, for example, Hanley, Shogren and White (1997: 352-3). A complete model would combine all values.

pinch out is no more reason to neglect the potential contribution of forests than the observation that the total supply of a nonrenewable resource is limited is reason not to utilize the resource. Rather, the analysis in terms of present values points out that a relatively cheap current solution, even if temporary, can successfully be adopted in order to postpone the need to adopt costlier ones. As in the case of nonrenewable resources, this observation is even more important if society anticipates that technological change may lower the cost of alternatives over time.

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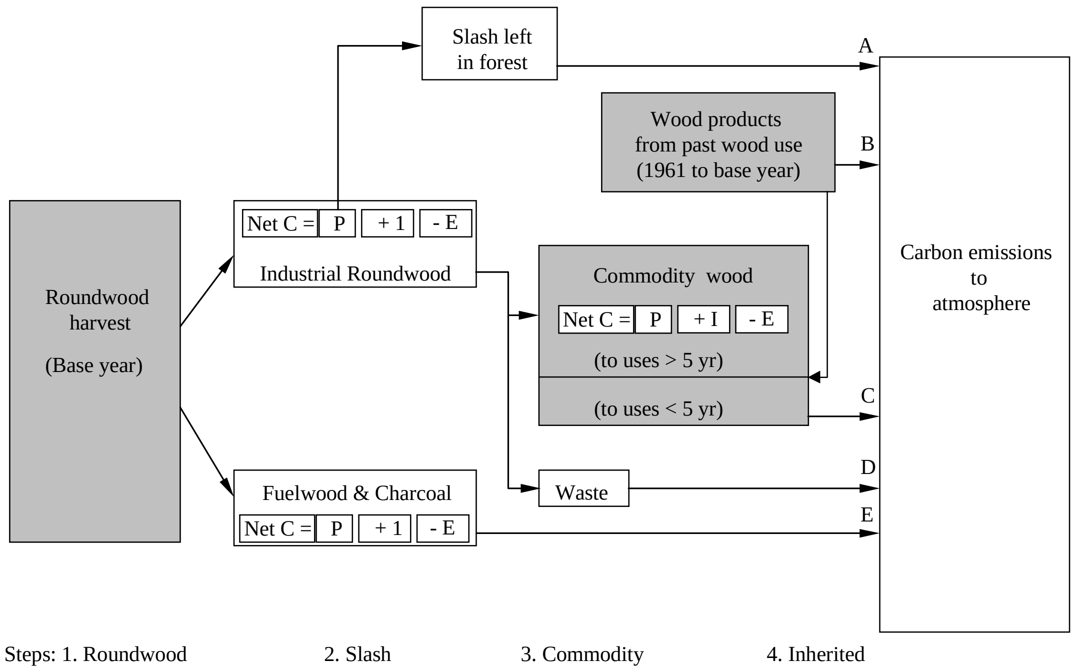

Figure 1. (reproduced from Winjum et al. (1998)). Diagram of steps used in the atmospheric-flow method for computing estimates of a country's annual carbon emissions to the atmosphere from forest harvests and use of wood products. C = consumption, P = production, I= imports, and E = exports. The arrows to the box labeled carbon emissions to the atmosphere represent the C fluxes due to A – decomposition of slash, B – oxidation or decay of long-term wood products (> 5 yr) from past use (inherited emissions), C – oxidation of wood products with short-term (< 5 yr) uses, D – oxidation of waste (burning or decaying) from the production of commodities, and F – burning of fuelwood and charcoal. The shaded boxes are those used in calculations for the stock-change method.