Review of Income and Wealth
Series 45, Number 2, June 1999

NET ACCUMULATION OF TIMBER RESOURCES

BY JEFFREY R. VINCENT

Harvard Institute for International Development

National accounting issues related to forest resources have attracted much attention recently. The net-depletion method, the most popular method for estimating aggregate changes in the value of timber stocks, tends to overstate both the depreciation of mature forests due to harvests and the appreciation of immature forests due to growth. Alternative, correct methods, which I term the net-price and El Serafy variations, can be derived from an asset valuation model that takes forest age into account. An empirical example indicates that estimates from the net-depletion method can deviate from actual values by up to 40 percent for some age classes.

1. INTRODUCTION

Wasting Assets by the World Resources Institute (Repetto *et al.*, 1989), which analyzed the depletion of petroleum, timber, and agricultural soils in Indonesia, sparked considerable interest in environmental adjustments to national income accounts. Similar studies have subsequently been conducted in many other countries (Sheng, 1995; Hamilton and Lutz, 1996). International organizations like the United Nations and the World Bank have endorsed these efforts by organizing symposia (Ahmad *et al.*, 1989; Lutz, 1993), sponsoring research (World Bank, 1997), and preparing handbooks on improved accounting procedures (United Nations, 1993; FAO, 1996).

In the past couple of years, considerable attention has focused on accounting issues related to forest resources. The "London Group" of national accountants devoted a full session of its 1996 annual meeting to forest accounting issues (Statistics Sweden, 1996). Also in 1996, the U.S. National Academy of Sciences established an expert panel to examine environmental issues in the national accounts, with a subpanel focusing on forest resources. In late 1996, the U.N. Food and Agriculture Organization launched a project to prepare a handbook on forest accounting. A review conducted for that project identified more than 30 forest accounting studies conducted in more than 20 countries since 1989 (Vincent and Hartwick, 1997).

This paper focuses on one specific forest accounting issue: changes in the asset value of timber stocks. Standing timber is a form of natural capital whose depreciation due to harvests, fire and pest damage, and other factors should in theory be subtracted from gross domestic product (GDP) in calculating net domestic product (NDP) (Hartwick, 1990, 1992; Mäler, 1991).[1] Furthermore, as timber is a renewable resource, NDP should reflect not only negative adjustments related to depreciation but also positive adjustments related to regeneration and

Note: The research reported in this paper was initiated with funding from the U.N. Food and Agriculture Organization and completed with funding from the AVINA Foundation.

[1] Conventional NDP equals GDP minus the depreciation of human-made or physical capital.

growth. I label the difference between the appreciation and depreciation of timber stocks "net accumulation," as the accumulation accounts are where changes in asset values are recorded within the national accounts (Inter-Secretariat Working Group on National Accounts, 1993, p. 33). The difference may also be regarded as the implicit *net investment* in timber resources.

The paper examines the analytical foundations of methods for estimating the net accumulation of timber. It begins by reviewing estimation methods for nonrenewable resources. It then reviews the net-depletion method for renewable resources, which generalizes methods for nonrenewable resources without taking into account the time lags that occur between timber harvests. This simplification tends to cause the net-depletion method to overstate both the decrease in forest value that occurs when mature forests are logged and the increase that occurs as immature forests grow. The paper presents alternative methods that avoid these biases. It examines the potential empirical magnitude of the bias by considering the example of timber growth and yield in Southeast Asian rainforests.

The approach in this paper is somewhat similar to that in an appendix to a paper by Newson and Gié (1996). I push the analysis further, however, and draw a more direct comparison to existing estimation methods, specifically the net-price method and El Serafy's method.

2. Net Accumulation for a Nonrenewable Resource

The asset value of a natural resource, whether nonrenewable or renewable, equals the discounted sum of the net returns (resource rents) it generates over time. Net accumulation refers to the change in asset value from one period to the next. In the general case, net accumulation can be either positive or negative. It can be positive even in the case of nonrenewable resources, if rising prices generate large holding gains. For the most part, this paper ignores the issue of holding gains. For a treatment of this issue in the case of nonrenewable resources, see Vincent, Panayotou, and Hartwick (1997).

Under the assumption of a constant price for the extracted resource, the asset value of a deposit of $S(t)$ units of a nonrenewable resource at time t is therefore given by

$$V(t) = \sum\{(1+i)^{t-s}[pq(s) - C(q(s))]\} \tag{1}$$

where this sum and the stock constraint

$$S(t) = \sum q(s)$$

are evaluated over the interval $s = t, \ldots, T$, with T being the terminal time (the period when the deposit is exhausted). i is the discount rate, p is the price of one unit of the extracted resource, $q(s)$ is the quantity extracted in period s, and $C(q(s))$ is the total extraction cost. The difference $pq(s) - C(q(s))$ is current resource rent.

By separating out resource rent in period t, which is not discounted, from the discounted sum in (1), we can equivalently express asset value as

$$V(t) = pq(t) - C(q(t)) + V(t+1)/(1+i) \tag{2}$$

where $V(t+1)$ is asset value in period $t+1$.[2] Net accumulation during period t is defined as

$$N(t) \equiv V(t+1) - V(t). \tag{3}$$

Substituting (2) into this expression, we obtain

$$N(t) = iV(t+1)/(1+i) - [pq(t) - C(q(t))]. \tag{4}$$

This is the fundamental equation of asset equilibrium (Hartwick and Hagemann, 1993). It indicates that net accumulation is the difference between two opposing forces: the shifting of the discounted stream of future rents toward the present, which increases asset value, and the realization of current resource rent, which decreases asset value.

In a continuous-time formulation, Hartwick (1977, 1990; see also Hartwick and Hageman, 1993) demonstrated that (4) simplifies to the negative of the product of marginal rent and quantity extracted,[3]

$$N(t) = -[p - C'(q(t))]q(t). \tag{5}$$

This result requires prices, the extraction cost schedule, and the discount rate to be constant over time and the extraction program to be optimal (Hotelling's r-percent rule holds). Hartwick labeled the product of marginal rent and quantity extracted "Hotelling rent." The negative sign on this product in (5) indicates that net accumulation is negative—the second term in (4) outweighs the first—but is smaller in absolute value than current resource rent. The intuition is that current resource rent can be divided into two components, Hotelling rent and inframarginal rent. The latter equals the first term in (4) along a dynamically optimal extraction path, leaving the negative of Hotelling rent as the difference between it and resource rent (the second term).

The expression given by (5) is the correct version of the *net-price method* for a nonrenewable resource.[4] What is obviously attractive about this method is that it allows one to calculate net accumulation using only current data on price, marginal extraction cost, and quantity extracted. One does not need projections of future rents, which are needed to calculate $V(t+1)$ in (4).

An alternative, theoretically equivalent method for estimating net accumulation uses the marginal cost elasticity: $\beta = C''(q(t))q(t)/C'(q(t))$. This method involves multiplying the negative of current resource rent times a conversion factor involving the discount rate, the number of years until exhaustion $(T-t)$, and

[2]Peskin (1989) presented a similar derivation.

[3]In discrete time, marginal rent in (5) must be lagged one period (Hartwick, 1995).

[4]The incorrect method is to multiply the negative of quantity extracted times average rent (price minus average cost). This yields current resource rent and ignores the effect of the first term in (4). Most applied studies have used average rent instead of marginal rent and have consequently tended to overstate the reduction in asset values due to natural resource depletion.

the elasticity (Vincent, 1997):

$$N(t) = -[pq(t) - C(q(t))]\{(1+\beta)/[1+\beta(1+i)^{T-t}]\}. \tag{6}$$

The term in curly brackets equals the ratio of Hotelling rent to current resource rent. (6) may be regarded as the generalized form of the *El Serafy method*. The original version of this method (El Serafy, 1989; Hartwick and Hagemann, 1993),

$$N(t) = -[pq(t) - C(q(t))]/(1+i)^{T-t},$$

implicitly assumes that $\beta = \infty$. Though much simpler to apply, this version yields accurate estimates of net accumulation only if the marginal cost curve is indeed infinitely elastic.

3. The Net-Depletion Method for a Renewable Resource

The seemingly intuitively obvious way to extend the nonrenewable resource model in the previous section to a renewable resource like timber is to modify (5) to include growth of the resource, $g(t)$:

$$N(t) = -[p - C'(q(t))][q(t) - g(t)]. \tag{7}$$

This is the method presented in Mäler (1991) and applied, with some modification, by Vincent (1997). I refer to it as the *net-depletion method*. With marginal cost replaced by average cost, it is the method used in Repetto *et al.* (1989) and most other applied studies that have attempted to incorporate timber depletion into the national accounts (Vincent and Hartwick, 1997). It is also among the methods highlighted in the guidelines for the United Nations' System of Integrated Environmental and Economic Accounting (United Nations, 1993, pp. 60–66).

Although the net-depletion method might seem to be a reasonable generalization of the net-price method, it generally does not yield accurate estimates of net accumulation of timber. Demonstrating this is easier if we assume that timber stands are even-aged (all timber trees in a given stand are the same age) and if we disaggregate the forest by age class, y (year), where Y indicates the mature age class (the age when the forest is harvested). Suppose that $A(Y)$ hectares of mature forest are harvested in a given period, while $A(y)$ hectares of immature forests of ages $y = 1, \ldots, Y-1$ are left to grow.[5] Assuming that all standing timber is harvested at the rotation age Y, with no intervening production from thinnings, and that $q_h(Y)$ is the standing timber volume per hectare in mature forests, then total harvest, $q(t)$ in (7), equals $A(Y)q_h(Y)$. Similarly, total timber growth, $g(t)$ in (7), equals $\sum A(y)q_h'(y)$, where $q_h'(y)$ is the derivative of the timber volume function and the sum is evaluated over all immature age classes, $y = 1, \ldots, Y-1$.

Substituting age classes into (7) yields

$$N(t) = -[p - C'(q_h(Y))][A(Y)q_h(Y) - \sum A(y)q_h'(y)].$$

[5]To simplify notation, we omit the time period t from $A(Y(t))$ and subsequent age-class expressions.

This implies the following *per-hectare* net accumulation values for mature and immature forests:

Net-depletion method

(8a) Mature forest: $N_h(Y) = -[p - C'(q_h(Y))]q_h(Y)$

(8b) Immature forest: $N_h(y) = [p - C'(q_h(Y))]q_h'(y)$.

The first expression states that net accumulation for one hectare of mature forest equals the negative of the product of marginal rent and volume harvested. This is analogous to expression (5) for a nonrenewable resource. Of course, renewable and nonrenewable resources differ due to the fact that the former can regenerate. Following harvest, the area that is currently mature forest becomes immature forest that regenerates and yields future harvests. For this reason, one should suspect that (8a) is incorrect. It includes the negative effect of current harvest on net accumulation but not the positive effect of future harvests.

The second expression states that net accumulation for one hectare of immature forest equals the product of marginal rent for mature timber and the volume of current growth. As the growing timber is not yet mature, valuing it by the same marginal rent as mature timber would appear to be inappropriate. One would expect that net accumulation should somehow reflect the number of years until harvest.

These suspicions about the net-depletion method turn out to be well-founded. In the next two sections, we formally demonstrate this and derive two alternative, but equivalent, sets of expressions that yield correct estimates of net accumulation.

4. The El Serafy Variation for Timber

Timber rotations typically span several decades. The asset value of an individual hectare of forest managed in perpetuity for timber production is, from basic forest economics (Pearse, 1990, ch. 7),

Asset values

(9a) Mature forest: $V_h(Y) = [pq_h(Y) - C(q_h(Y))]/[1 - (1 + i)^{-Y}]$

(9b) Immature forest: $V_h(y) = (1 + i)^{y - Y}[pq_h(Y) - C(q_h(Y))]/[1 - (1 + i)^{-Y}]$.

We can derive a correct method for estimating net accumulation by inserting these expressions into (3). Consider the mature forest first. An instant before harvesting, asset value equals (9a). One period later, age class (y) equals 1, and asset value equals

(10) $$V_h(1) = (1 + i)^{1 - Y}[pq_h(Y) - C(q_h(Y))]/[1 - (1 + i)^{-Y}].$$

Net accumulation for one hectare of mature forest is thus

$$N_h(Y) = V_h(1) - V_h(Y),$$

which yields

(11) $$N_h(Y) = iV_h(1)/(1+i) - [pq_h(Y) - C(q_h(Y))]$$

after substituting (9a) and simplifying. This is the analogue to (4). Net accumulation reflects both the realization of rents from the current harvest, which decreases asset value, and the shifting of rents from future harvests toward the present, which increases asset value. Substituting (10) for $V_h(1)$, we obtain

$$N_h(Y) = -[pq_h(Y) - C(q_h(Y))]\{[1-(1+i)^{1-Y}]/[1-(1+i)^{-Y}]\}.$$

As this relates net accumulation to current resource rent, it is the forestry analogue to (6). Hence, I refer to it as the *El Serafy* variation.

Now, consider the immature case. Through steps similar to those in the preceding paragraph, we obtain

$$\begin{aligned} N_h(y) &= iV_h(y) \\ &= [pq_h(Y) - C(q_h(Y))]\{i(1+i)^{y-Y}/[1-(1+i)^{-Y}]\}. \end{aligned}$$

As in the mature case, net accumulation involves the product of per-hectare rent from harvesting the mature forest and a discounting term. The latter term differs, however, with a key difference being that it includes current age as well as the rotation age.

Summing up, we have:

El Serafy variation

(12a) Mature forest: $$N_h(Y) = -[pq_h(Y) - C(q_h(Y))]\{[1-(1+i)^{1-Y}]/[1-(1+i)^{-Y}]\}$$

(12b) Immature forest: $$N_h(y) = [pq_h(Y) - C(q_h(Y))]\{i(1+i)^{y-Y}/[1-(1+i)^{-Y}]\}.$$

Two obvious differences compared to El Serafy's method for nonrenewable resources given by (6) are that the marginal cost elasticity is absent and that the discounting terms are more complex. These differences are related. As demonstrated by the derivations, the discounting terms reflect the dynamics of changes in timber asset values. The same is true for El Serafy's method for nonrenewable resources (see Vincent, 1997). The discounting term is simpler in that case, however, due to the simpler dynamics of annual, exhaustible mineral production compared to periodic, perpetual timber production.

Regarding the elasticity, dynamics in the nonrenewable case are driven by Hotelling's rule, which pertains to changes in marginal rent. Expression (6) includes the elasticity because it links marginal and average rents. Dynamics in the case of timber, on the other hand, are driven by the forest growth function, which is independent of the marginal cost curve.

Finally, we can observe that the term in curly brackets in (12a) will be approximately equal to 1 for most plausible combinations of i and Y, which implies that $N_h(Y)$ tends toward current rent, $-[pq_h(Y) - C(q_h(Y))]$.

5. The Net-Price Variation for Timber

The Faustmann "optimal rotation" condition states that a forest should be harvested when

$$(13) \qquad [p - C'(q_h(Y))]q_h'(Y)/[pq_h(Y) - C(q_h(Y))] = i/[1 - (1+i)^{-Y}].$$

That is, it should be harvested when the rate of growth in timber value equals the opportunity cost of funds, where the latter is adjusted for the effect of the current harvest decision on the timing of future harvests (Pearse, 1990, ch. 7).[6] Rearranging, we obtain

$$[pq_h(Y) - C(q_h(Y))]/[1 - (1+i)^{-Y}] = [p - C'(q_h(Y))]q_h'(T)/i,$$

which can be substituted into (12a) and (12b) to yield

Net-price variation

$$(14a) \quad \text{Mature forest:} \qquad N_h(Y) = -[p - C'(q_h(Y))]q_h'(Y)[1 - (1+i)^{1-Y}]/i$$

$$(14b) \quad \text{Immature forest:} \quad N_h(y) = [p - C'(q_h(Y))]q_h'(Y)(1+i)^{y-Y}.$$

I refer to these expressions as the *net-price variation*, because they involve marginal rent and are therefore analogues to (5).

Note that the net-price variation is derived from an assumption that the timber rotation is optimal. Derivation of the El Serafy variation did not involve this assumption, and in this sense the El Serafy variation is more generally applicable. Another advantage of the El Serafy variation is that it requires data on timber harvest volumes, which are more commonly available than data on growth rates.

(14a) and (14b) can be readily compared to (8a) and (8b) for the net-depletion method. Two differences are immediately obvious. First, (8a) includes the *harvest* at the rotation age, while (14a), the correct expression for mature forests, includes *growth* at the rotation age. Second, (8b) includes *current growth*, while (14b), the correct expression for immature forests, includes *growth at maturity*. The comparison is complicated, however, by the discounting terms in (14a) and (14b). Let us consider the two pairs, (8a) and (14a) for mature forests and (8b) and (14b) for immature forests, more carefully in turn.

The ratio of (8a) to (14a) is

$$\{q_h(Y)/q_h'(Y)\}\{i/[1 - (1+i)^{1-Y}]\}.$$

Solving (13) for $q_h(Y)$ and substituting the result into this expression, we obtain

$$(15) \quad \{[p - C'(q_h(Y))]/[p - C(q_h(Y))/q_h(Y)]\}\{[1 - (1+i)^{-Y}]/[1 - (1+i)^{1-Y}]\}.$$

Under the standard neoclassical assumption that marginal cost is greater than or equal to average cost, the first term in curly brackets is less than or equal to one. The second term is unambiguously greater than one. The net-depletion method can therefore either overstate or understate depreciation of mature forests. The former is more likely to be the case in practice, as marginal and average logging

[6]Forest economists often assume that the cost function is linear: $C(q_h(Y)) = cq_h(Y)$. Then, the left-hand side of (13) reduces to $q_h'(Y)/q_h(Y)$.

costs often do not vary much within individual logging units, especially small, homogeneous ones. When marginal and average costs are exactly equal, (15) simplifies to just the second term. Given that the numerator and denominator of the second term differ by just a single $(1+i)$ term, the bias in the net-depletion method is then unlikely to be very large unless the discount rate is large.

Estimates from (8b) are also likely to be larger than estimates from (14b). The ratio of the former to the latter is

$$(1+i)^{Y-y}[q_h'(y)/q_h'(Y)]. \tag{16}$$

Economists usually assume that the function relating timber volume to age $(q_h(y))$ has either a concave or a logistic shape (Pearse, 1990, ch. 7; Hartwick, 1993). In the latter case, they usually assume that the inflection point occurs at a relatively young age. Data from actual forests generally support these assumptions. Hence, for all ages in the case of concave volume functions, and most ages in the case of logistic functions, $q_h'(y) > q_h'(Y)$: the marginal timber growth rate declines as the forest ages.[7] For this reason alone, (16) would tend to be larger than one, but it is increased further by the compounding term.

In sum, we expect the net-depletion method to overstate the appreciation of immature forests, except in very young forests with a logistic volume-age relationship. The magnitude of the upward bias declines as the forest matures, both because the exponent in the compounding term becomes smaller and because $q_h'(y)$ converges toward $q_h'(Y)$.

6. An Empirical Comparison

Both the El Serafy and net-price variations for timber are considerably more complex than their counterparts for nonrenewable resources, and more complex than the net-depletion method for renewable resources. If the estimates they generate are only slightly better than those from the net-depletion method, then applying them might not be worth the extra information required. This includes data on the area of a country's forest estate by age class, and per-hectare data on timber growth rates (the net-price variation) or timber harvest volumes (the El Serafy variation).

Table 1 compares estimates of net accumulation from the net-depletion method to correct estimates calculated directly as the difference between asset values (calculated using (9a) and (9b)). The El Serafy and net-price variations yield estimates identical to the latter, as they are derived from it. The data are drawn from dipterocarp forests in Malaysia. The relationship between standing volume per hectare (net of defect) and age is given by

$$q_h(y) = 0.65 \times 132 \times e^{1-60/y},$$

which has a logistic shape. Real log price (p) is RM 115/m^3 (1978 base year), where 1 RM (ringgit Malaysia) ≅ US\$0.40 at the time of writing. The logging cost function is linear, $C(q_h(Y)) = cq_h(Y)$, with c = RM 45/m^3. The discount rate is 4 percent in real terms. Under these assumptions, the Faustmann formula implies

[7]What foresters term the "current annual increment."

TABLE 1
COMPARISON OF NET ACCUMULATION ESTIMATES

Characteristics of forest				Net accumulation	
Age (y) (year)	Volume $(q_h(y))^a$ (m^3/ha)	Growth $(q_h'(y))^b$ (m^3/ha/yr)	Asset value $(V_h(y))^c$ (RM/ha)	Correct value (RM/ha)	Net-depletion method (RM/ha)
1	0.0	0.00	1,041	42	0
2	0.0	0.00	1,082	43	0
3	0.0	0.00	1,126	45	0
4	0.0	0.00	1,171	47	0
5	0.0	0.00	1,217	49	0
6	0.0	0.02	1,266	51	1
7	0.0	0.05	1,317	53	4
8	0.1	0.12	1,369	55	8
9	0.3	0.22	1,424	57	15
10	0.6	0.35	1,481	59	24
11	1.0	0.49	1,540	62	35
12	1.6	0.65	1,602	64	46
13	2.3	0.82	1,666	67	57
14	3.2	0.98	1,733	69	69
15	4.3	1.14	1,802	72	80
16	5.5	1.29	1,874	75	90
17	6.8	1.42	1,949	78	99
18	8.3	1.54	2,027	81	108
19	9.9	1.65	2,108	84	115
20	11.6	1.74	2,193	88	122
21	13.4	1.82	2,280	91	128
22	15.3	1.89	2,371	95	132
23	17.2	1.95	2,466	99	136
24	19.1	1.99	2,565	103	140
25	21.2	2.03	2,668	107	142
26	23.2	2.06	2,774	111	144
27	25.3	2.08	2,885	115	146
28	27.4	2.09	3,001	120	147
29	29.5	2.10	3,121	125	147
30	31.6	2.10	3,245	130	147
31	33.7	2.10	3,375	135	147
32	35.8	2.10	3,510	140	147
33	37.9	2.09	3,651	–2,610	–2,650

Notes: (a) $q_h(y) = 0.65 * 132 * e^{1-60/y}$.
(b) $q_h'(y) = 60 * q_h(y)/y^2$.
(c) $V_h(y)$: see (9a–b). p = RM 115/m^3, c = RM 45/m^3, i = 4%, Y = 33 yrs.

an optimal rotation age (T) of 33 years. The harvest is 37.9 m^3/ha, and the resource rent generated by the harvest is RM 2,650/ha.

As predicted, estimates from the net-depletion method differ from the correct estimates. Given the logistic volume-age relationship, the net-depletion method understates the appreciation of young forests (through age 13), but beyond that point it overstates it, by up to 40 percent. It overstates the depreciation of the mature forest by only 1.5 percent, which is small both in absolute terms and relative to the discrepancies for the immature forest.

Since the net-depletion method tends to overstate both the appreciation of immature forests and the depreciation of mature forests, the biases are to some extent offsetting for a forest estate that includes a mix of mature and immature forests. The overall bias depends on the relative areas of forests in different age classes. If the forest estate consists primarily of mature and very immature forests, which is more likely to be true in developing countries, then the net-depletion method will tend to produce downward biased estimates of net accumulation. The asset value of the forest estate will appear to be falling more rapidly than it actually is. In contrast, if the forest estate consists primarily of well-established immature forests, which is more likely to be true in developed countries, then the net-depletion method will tend to produce upward biased estimates. The value of the forest estate will appear to be rising more rapidly than it actually is.

A couple of simple examples illustrate the potential magnitude of the error associated with using the net-depletion method to estimate net accumulation at an aggregate (e.g. national) level. Suppose that 90 percent of the forest estate is mature and 10 percent is 10 years old. Then net accumulation expressed on an average hectare basis is –RM 2,343 (= (0.9 × –RM 2,610) + (0.1 × RM 59)). The net-depletion method generates an estimate that is virtually identical, –RM 2,383 (= (0.9 × –RM 2,650) + (0.1 × RM 24)). On the other hand, if all the forest estate is of medium age, say 17 years, then the net-depletion method overstates actual appreciation by 27 percent (RM 99 per hectare vs. RM 78 per hectare). Perhaps the most interesting example is the following. Suppose that 5 percent of the forest estate is 33 years old and 95 percent is 24 years old. With this age class structure, timber growth exactly equals harvest. Hence, the net-depletion method yields a value of zero.[8] Actual net accumulation is –RM 33 on a hectare basis, however. This result indicates that net accumulation does not necessarily equal zero when aggregate growth equals aggregate harvest.

Only in the case of a so-called "normal" forest estate, which has equal areas in each age class, does the net-depletion method yield an unbiased estimate of net accumulation. In that special case, net accumulation trivially equals zero, because the age-class structure of the forest is stationary from one period to the next. Neither appreciation nor depreciation occurs. Unfortunately for the net-depletion method, "normal" forests are more common in forestry textbooks than in the real world. In the unlikely event that a country's forest estate is indeed "normal," there is no need to apply the net-depletion method, or any other method for that matter, as one knows *a priori* that net accumulation equals zero. Hence, in the sole case where it yields accurate estimates, the net-depletion method is not needed.

7. Conclusions

By ignoring forest age, the net-depletion method tends to overstate both the negative impact of harvesting and the positive impact of growth on the asset value of timber resources. The latter bias is likely to be greater in practice. Fortunately,

[8]Calculating the estimate for the net-depletion method by using values in the last column of Table 1, instead of by subtracting growth from harvest (both equal to 37.9 m^3) and multiplying by net price (RM 70/m^3), yields a value slightly less than zero. This is due to slight differences between growth rates calculated by the derivative of the volume function, $q_h'(y)$, which is how the growth rates are calculated in Table 1, and growth rates calculated by the difference in standing volumes, $q_h(y+1) - q_h(y)$. The sum is indeed zero if growth rates are calculated by the latter expression.

two other methods that yield correct estimates can be applied, the net-price variation and the El Serafy variation. Compared to the net-depletion method, these methods require additional information on forest area by age class, the discount rate, and the rotation age.

Four of the assumptions made in the course of the analysis in this paper can be rather easily relaxed, at least in approximate fashion. First, the analysis assumed that timber is the only economically significant forest product. In fact, the net-price and El Serafy variations can be applied to any forest product that is produced on a periodic basis. Fuelwood, rattan, and bamboo are examples of products that fit this description.

Second, the analysis assumed that forests are even-aged. As long as harvests are approximately the same each time a stand is harvested, the two methods can be applied to uneven-aged forests by redefining key variables. For example, suppose a forest contains three age classes, with the rotation age (the chronological age of mature trees) being 60 years. Then the cutting cycle, the frequency of harvest, is 20 years. In the expressions for the net-price and El Serafy variations, Y, the rotation age (60 years), should be replaced by the cutting cycle (20 years) whenever it appears in asssociation with the discount rate (e.g. in the term $(1+i)^{1-Y}$). $q_h(Y)$ still represents the amount of timber harvested per hectare, but this is now less than the standing volume, since some of the standing volume is in immature age classes. Similarly, $q_h'(Y)$ now represents only growth of mature timber. y is now the number of years since the last harvest, not the chronological age of trees. $Y-y$ still represents the number of years until the next harvest.

Third, the analysis assumed that log prices are constant over time. This is not necessarily cause for concern. Given the long time periods involved in timber production, holding gains are not an important long-run issue if they are ephemeral, i.e. if prices show no persistent trend over time. In that case, a practical solution is to use a moving average of prices to remove the effects of more extreme transitory fluctuations. The matter is more serious if price trends are persistent. Changing log prices imply changing marginal rents. If log prices change at an approximately constant percentage rate over time, and if marginal cost is approximately proportional to log price, then the rate of change in log prices translates into approximately the same rate of change in marginal rent. A trend in marginal rents can be crudely reflected in the analysis by adjusting the discount rate. For example, if the discount rate is 10 percent and marginal rent is rising at 2 percent, one can calculate net accumulation by using an adjusted discount rate of 8 percent. Although this is a crude way of dealing with price trends, it might yield more accurate estimates than ignoring the trends altogether.

Finally, the analysis assumed that harvest and growth are the only factors affecting timber stocks. This is, of course, not the case in reality. Fire, pests, natural disasters, and forest conversion (deforestation) can all destroy valuable timber. In the first three cases, if the standing timber stock is destroyed but the forest regenerates, the loss in asset value on a per-hectare basis equals $V_h(0) - V_h(y)$, where y is the age of the forest when disaster strikes. On the other hand, if the forest fails to regenerate, the change in asset value equals $L_h - V_h(y)$, where L_h is the value of the land in its new use. The same expression would be applied to the case of deforestation. The key point is that one must account for the asset value of land in not only its former forestry use but also in its new, nonforestry use (Hartwick, 1992, 1993).

References

Ahmad, Y., S. El Serafy, and E. Lutz, eds., *Environmental Accounting for Sustainable Development*, World Bank, Washington, D.C., 1989.

El Serafy, S., The Proper Calculation of Income from Depletable Natural Resources, in Y. Ahmad, S. El Serafy, and E. Lutz, eds., *Environmental Accounting for Sustainable Development*, World Bank, Washington, D.C., 1989.

FAO, *A System of Economic Accounts for Food and Agriculture*, Statistical Development Series No. 8, Rome, 1996.

Hamilton, K. and E. Lutz, Green National Accounts: Policy Uses and Empirical Experience, Environmental Economics Series Paper No. 039, Environment Department, World Bank, Washington, D.C., 1996.

Hartwick, J. M., Natural Resources, National Accounting, and Economic Depreciation, *Journal of Public Economics*, 43, 291–304, 1990.

———, Deforestation and National Accounting, *Environmental and Resource Economics*, 2, 513–21, 1992.

———, Forestry Economics, Deforestation, and National Accounting, in E. Lutz, ed., *Toward Improved Accounting for the Environment*, World Bank, Washington, D.C., 1993.

———, A Discrete-Time Savings Rule for Constant Consumption with Exhaustible Resources, mimeo, Queen's University, Kingston, Ontario, 1995.

——— and A. Hageman, Depreciation of Mineral Stocks and the Contribution of El Serafy, in E. Lutz, ed., *Toward Improved Accounting for the Environment*, World Bank, Washington, D.C., 1993.

Inter-Secretariat Working Group on National Accounts, *System of National Accounts 1993*, Commission of the European Communities—Eurostat, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, and World Bank, 1993.

Lutz, E., ed., *Toward Improved Accounting for the Environment*, World Bank, Washington, D.C., 1993.

Mäler, K.-G., National Accounts and Environmental Resources, *Environmental and Resource Economics*, 1, 1–15, 1991.

Newson, B. and G. Gié, Forest Economic and Environmental Accounting, in *Third Meeting of the London Group on Natural Resource and Environmental Accounting*, Statistics Sweden, Stockholm, 1996.

Pearse, P. H., *Introduction to Forestry Economics*, UBC Press, Vancouver, 1990.

Peskin, H. M., Accounting for Natural Resource Depletion and Degradation in Developing Countries, Environment Department Working Paper No. 13, World Bank, Washington, D.C., 1989.

Repetto, R., W. Magrath, M. Wells, C. Beer, and F. Rossini, *Wasting Assets: Natural Resources in the National Income Accounts*, World Resources Institute, Washington, D.C., 1989.

Sheng, F., *Real Value for Nature*, WWF International, Gland, Switzerland, 1995.

Statistics Sweden, *Third Meeting of the London Group on Natural Resource and Environmental Accounting*, Stockholm, 1997.

United Nations, *Integrated Environmental and Economic Accounting: Interim Version*, Handbook of National Accounting, Studies in Methods, Series F, No. 61, New York, 1993.

Vincent, J. R., Resource Depletion and Economic Sustainability in Malaysia, *Environment and Development Economics*, 2, 19–37, 1997.

——— and J. M. Hartwick, Accounting for the Benefits of Forest Resources: Concepts and Experience, report prepared for the U.N. Food and Agriculture Organization, mimeo, Rome, 1997.

———, T. Panayotou, and J. M. Hartwick, Resource Depletion and Sustainability in Small Open Economies, *Journal of Environmental Economics and Management*, 33, 274–86, 1997.

World Bank, *Expanding the Measure of Wealth: Indicators of Environmentally Sustainable Development*, Indicators and Environmental Valuation Unit, Environment Department, Washington, D.C., 1997.