Natural Resource Accounting for Thailand's Forests: A Theoretical Framework

Alexandra Lai

ISSN 1192-6082

Preface

This John Deutsch Institute (JDI) publications series arises from our CIDA-supported projects with the Thailand Development Research Institute (TDRI) and the Malaysian Institute of Economic Research (MIER). Central to these projects is the collaboration by Canadian, Malaysian and Thai researchers. These monographs are intended to make research results available to broader Canadian and international audiences. We are grateful to CIDA for its financial support.

Alex Lai undertook a CIDA-sponsored internship at TDRI in the summer of 1996 to assist the Natural Resources and Environment (NRE) program with their project on natural resource accounting. Her principal assignment was to assist in the review and development of methodologies for the forest sector. The results of this work, which are presented in this monograph, were an important input into the empirical estimates prepared later under the direction of Dr. Direk Patmasiriwat.

Frank Flatters
Associate Director, JDI and
Director, TDRI and MIER Projects

April 1997

Natural Resource Accounting for Thailand's Forests: A Theoretical Framework

Alexandra Lai

I. INTRODUCTION

Thailand is endowed with abundant natural resources and a varied topography and climate. These natural assets have been exploited in Thailand to further economic development, as has been the case in most countries fortunate enough to be faced with the option. In the process of economic development, Thailand has depleted much of its natural resources, with a notable example being its forests.

We have come to recognize that a country's natural resource constitutes part of its capital. The depreciation of human-made capital is reflected in national accounts and charged against income generated by its use to get conventional Net National Product (NNP). Depreciation is imputed to capture the declining income-generating potential of an asset over time, and indicates the level of investment necessary for an economy to maintain its productive capacity. The income generated by the use of man-made capital is thus recorded net of the investment required to maintain its future productivity. Yet, in current national accounts, depreciation is imputed and deducted only for reproducible man-made capital. Similarly, when natural capital is used up, the results is an economic depreciation of the stock of natural capital. This depreciation should also be netted out of the income generated by the use of the natural resource in

I would like to thank Professor Flatters and the staff at TDRI for their invaluable comments and supervision. Additionally, I would like to acknowledge the Canadian International Development Agency (CIDA) for granting me financial support at the Thailand Development Research Institute during which time I wrote this paper.

order to reflect fully the loss in future productivity that has occurred as a result of its depletion.

Thailand's economic success is reflected by dramatic gains in conventional economic indicators of growth, such as the gross domestic product (GDP), which have often been taken as indicators of an economy's welfare. Such indicators, however, focus exclusively on market transactions and hence whenever the market fails to reflect the full social value (or a change in value) of a resource, the economics indices do as well. Conventional economic indicators do not fully account for natural resource depletion. As well, resources like forests suffer from the fact that many of the services they provide are not valued in the economy (and hence do not have market value), thus leading to a further failure of national accounts to correctly reflect the national welfare of a resource-rich country which is rapidly depleting its natural resources.

This paper uses the theoretical framework developed by Hartwick (various years) for adjusting conventional national accounts to reflect the depletion of one of Thailand's most important natural resource — its forests. The second part of the paper looks at some studies that have attempted to calculate the adjusted NNP for other countries. The conclusion will discuss a few practical issues related to the construction of a green national product.

Thailand's Forest Resources

Thailand is host to a mix of forest types that can be classified into:

- *Topical Evergreen Forest* (EGF), the dominant type of evergreen forest in Thailand. This type of forest accounts for 43.3 percent of total forest area and is concentrated in regions with high rainfall (more than 2,000mm per year). These are widely distributed throughout southern Thailand and the mountainous areas of the north and west. Bamboo, vines and ferns provide the undergrowth and ground cover.

- *Mixed Deciduous Forest* (MDF), largely found at low elevations in the north and west, covering about 22 percent of the total forest area. Deciduous forests are characterized by leaf-shedding during the dry season.

- *Dry Deciduous Forest* (DDF), occupies about 30 percent of the total forest area. This is the main forest type in the north and northeast, and covers a wide range of elevations.

- *Pine Forest* (PF), usually located in small pockets in the north and northeast, primarily in mountainous areas. Only two pine species are native to Thailand.

- *Mangrove Forest* (MGF), a group of evergreen species generally found along river estuaries and muddy coastlines. About 73 percent of the mangrove forests in Thailand are found along the east and west coast of the southern peninsular.

All forest lands and forest resources in Thailand have been state property since 1899. Logging methods for concessions in productive forest areas have also been legislated. Selective cutting was the standard, and legally required, method of logging until 1985. The Fifth National Economic and Social Development Plan (1982-86) called for a shift from selective cutting to clear cutting in forest timber concessions, with the recommendation that replanting of logged areas take place immediately. This shift was based on the belief that clear cutting was more appropriate to prevailing socio-economic conditions, that natural forest regeneration has generally been inadequate, and that clear cutting requires, and hence affects, less total forest area. Currently, commercial logging is banned in Thailand. A ministerial decree terminated all forest logging concessions in January 1989.

Despite its long history of forest management, Thailand has been depleting its forest at an extremely high rate. At the beginning of the twentieth century, over 75 percent of Thailand was covered by forest. According to RFD statistics, natural forests covered some 27 million hectares, or about 53 percent of the total land area in Thailand in 1968. The country's natural forests were cleared at a rapid rate throughout the 1970s and 1980s mainly due to commercial logging and agricultural encroachment. By 1978, forest area had fallen to 34 percent of total land area, by 1988 to 28 percent. Tropical Evergreen Forests and Dry Diciduous Forests have suffered the heaviest losses.

Causes of deforestation include logging, encroachment for agricultural purposes and urban development. In Thailand, the predominant pattern of deforestation appears to have been one in which commercial logging ventures first enter and create access into the forests. They are then quickly followed by agricultural cultivation which prohibits regeneration of the natural forest.

II. THE THEORETICAL FRAMEWORK

The notion of GNP as a measure of "material" well-being is deeply rooted in the minds of generations of economists and policymakers. Here we examine the theoretical basis for using a national product concept as an index of well-being, and we show that in this capacity, conventional national product as it is calculated fails to take into account natural resources and hence gives an inaccurate measure of national welfare. We look at how a correct measure of national product as a welfare indicator can be calculated. Studies abound that assert the necessity of incorporating effects of natural resource depletion into national accounting measures without laying out the theoretical basis for it. We assert that a "green national product" should be based on a conceptual basis that permits a welfare-theoretic interpretation of the measure (Dasgupta *et al*., 1995).

National Product As A Welfare Measure

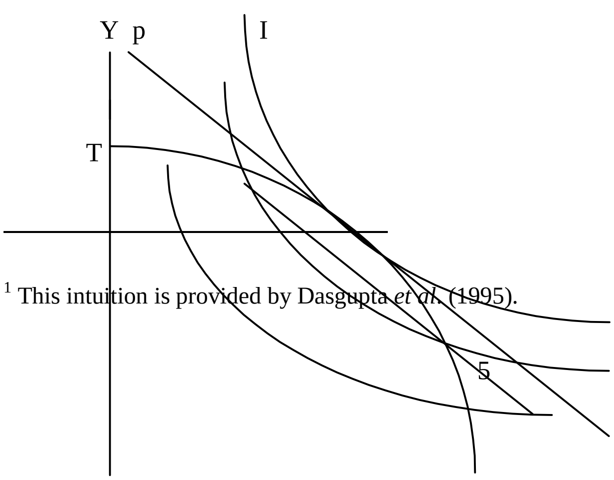
Here we present two ways of looking at the notion of national product as a welfare measure. The first is intuitive[1] and the second is based on Weitzman's (1976) results.

Net National Product has the property that, provided the set of accounting prices is unaffected, an improvement in the index owing to an alteration in economic activities reflects an increase in social well-being: small investment projects that improve the NNP index are at once those that improve social welfare. The emphasis on small projects is deliberate, for NNP is a linear index.

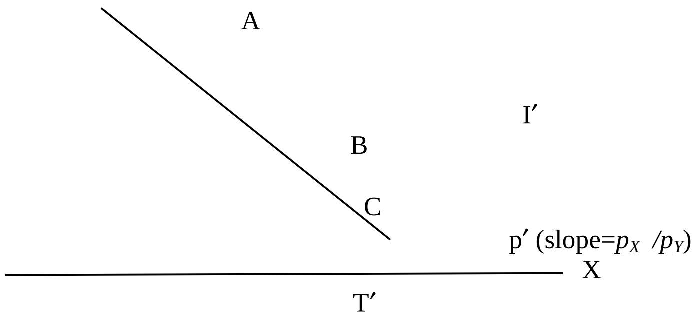
Consider an economy consisting of two consumer goods and a single individual. In Figure 1, X and Y denote the two goods and the curve TT' denotes the production possibility frontier (PPF). Let $U(X,Y)$ be the individual's welfare function and II´ the indifference curve which is tangential to TT' (corresponding to the maximum level of welfare attainable given the production possibilities set. We have assumed in Figure 1 that the production possibilities set is concave and $U(X,Y)$ a concave function. The tangent at *A*, denoted pp', defines optimal prices, $p_X \; / \, p_Y$. We may then define NNP at any production point (X,Y) as $p_X X + p_Y Y$. This is just the equation of the line with slope (p_X / p_Y) and the vertical intersection is just NNP.

Assume that the economy is at point C (on the PPF). We wish to check if a move to B (also on the PPF), which is an improvement in welfare, also records an increase in NNP. As Figure 1 shows, it does record in increase. Moreover, it can be confirmed that a move from C to any point of the PPF that records an increase in NNP also reflects an improvement in welfare.

Figure 1: Welfare Interpretation of National Product



[1] This intuition is provided by Dasgupta *et al*. (1995).



For points inside the production possibilities set, however, optimal prices (p_X , p_Y) are inappropriate for the estimation of NNP. Instead, local prices should be used. This illustrates the ideas. Take a consumption point (*X*,*Y*) inside the production possibilities set. Then the individual's welfare is *U*(*X*,*Y*). Now, consider a small change in consumption (dX, dY). To a first approximation, the resulting change in welfare is $U_X.dX + U_Y.dY$, where U_X and U_Y are the two partial derivatives of *U* at (X,Y). The change is desirable if $U_X.dX + U_Y.dY > 0$ and undesirable if $U_X.dX + U_Y.dY < 0$. Then U_X and U_Y could be used as accounting prices and NNP — evaluated on the basis of current marginal valuations is an appropriate measure of social well-being.

It is easily proved that the current value Hamiltonian of a neoclassical optimal growth problem is an economy's NNP. NNP is just a linearized version of the current value Hamiltonian, the linearization amounting to representing the current flow of well-being by the shadow price of all the determinants of current well-being.

Weitzman (1976) demonstrated that "the maximum welfare actually attainable from time t on along a competitive trajectory, $\int_t^\infty C^*(s)e^{-r(s-t)}ds$, is exactly the same as that would be obtained from the hypothetical constant consumption level $C^*(t) + p(t)\, d\dot{K}/dt$." K here is a vector of capital stocks that can be extended to include natural resource stocks and *p* is the vector of prices of the capital stocks relative to a unit of consumption good. Mathematically,

$$\int_t^\infty e^{-r(s-t)}\{C^*(t) + p(t)\dot{K}^*(t)\}\ ds = \int_t^\infty e^{-r(s-t)}C^*(s)ds$$

where $\dot{K}^*(t) - [F_R - f'(R^*(t))]R^*(t) = 0$. The integral on the left is the present value, from *t* on, of a constant consumption stream, and the integral on the right is just the present value of the optimal consumption path by which maximum welfare is obtained. As

$$\begin{aligned} Y^*(t) &= C^*(t) + p(t)\dot{K}^*(t) \\ &= r\int_t^\infty e^{-r(s-t)}\{C^*(t) + p(t)\dot{K}^*(t)\}\,ds \\ &= r\int_t^\infty e^{-r(s-t)}C^*(s)ds \end{aligned}$$

where $Y^*(t)$ is just NNP at time t.

The Simple Optimal Growth Model

We turn to a benchmark economy, and the usual standard is that of a well-behaved competitive general equilibrium, to develop principles of national accounting with natural resource stocks. The competitive equilibrium is handy to work with because, in such an economy relative prices reflect economic scarcity. The appropriate model here is a dynamic one — the Solow-Cass-Koopmans optimal growth model. We focus on the trade-off between dis-investing in exhaustible resource stock and investing/saving by not consuming from them. The same can be applied to renewable and environmental stocks. Stock depletion occurs as a consequence of consuming in excess of the renewal rate of such stocks and stocks increase when consumption is less than the natural renewal of stock. We view this stock increase from conservation as investment, or saving. The idea is that at each point in time, agents decide on the split of flows into current consumption and investment/saving. We begin with a simple optimal growth exercise without any natural resource.

We take the simplest representative agent model where there is no population growth and technology remains constant. The optimal growth problem is one of finding a sequence of consumption C(t) and investment $\dot{K}(t)$ that will maximize the agent's welfare, which is expressed as the discounted sum of period utility into the indefinite future.

$$\underset{c(t),\dot{K}(t)}{Max}\int_0^\infty e^{-\rho t}U(C(t))dt$$

s.t. $$\dot{K}(t) = F(K(t)) - C(t)$$

where $U(\bullet)$ is the period utility function of the agent, and $F(\bullet)$ is the output and $K(t)$ the accumulation of the capital stock.

The current value Hamiltonian associated with this problem is

$$H(t) = U(C(t)) + \lambda(t)[F(K(t)) - C(t)]$$

The first order condition, $\frac{\partial H}{\partial C} = 0$ gives us $H_C = \lambda(t)$. Dividing the current-value Hamiltonian by U_C, we obtain

$$\frac{H(t)}{U_C} = \frac{U(C(t))}{U_C} + \dot{K}$$

If we take the linear approximation $U(C) = U_C.C$, we get the result

$$\frac{H(t)}{U_C} = C + \dot{K}$$

Hence, the current-value Hamiltonian, normalized by the util value of a marginal unit of consumption defines, at each date, the NNP function, $C + I$. $H(t)$ is measured in utils and H/U_C is measured in dollars.

Extending For Natural Resources

Let $S(t)$ be the stock of exhaustible natural resource at time t,
$R(t)$ be the rate of depletion of the stock of resource,
$f(R)$ be the cost of depleting the stock, and
$F(K(t), R(t))$ be the production function for the composite commodity.

Now, the law of motion for "capital" is

$$\dot{K}(t) = F(K(t), R(t)) - C(t) - f(R(t)).$$

The current-value Hamiltonian is thus

$$H(t) = U(C(t)) + \lambda(t)[F(K(t), R(t)) - C(t) - f(R(t))] \\ + \varphi(t)[-R(t)]$$

where λ(t) is the shadow price of K(t) and φ(t) is the shadow price of S(t).

Our first order conditions are $\frac{\partial H}{\partial C} = 0$ and $\frac{\partial H}{\partial R} = 0$, which are just

$$\lambda(t) = U_C$$

and $$\varphi(t) = \lambda(t)[F_R - f'(R(t))] \Rightarrow \frac{\varphi(t)}{U_C} = F_R - f'(R(t))$$

Using the approximation $U(C) \approx U_C.C$ we obtain

$$NNP(t) \equiv \frac{H(t)}{U_C} = C(t) + \dot{K} - [F_R - f'(R)]R(t)$$

F_R $-f'(R)$ is just Hotelling rent. Hence, $[F_R - f'(R)]R(t)$ is total Hotelling rent. So, to allow for the depreciation of natural resource stocks, we simply subtract from conventional NP the total Hotelling rent. We call this the economic depreciation of the natural resource stock. This economic depreciation is the loss in value of a stock of natural resource from optimal use.

Following Hartwick's rule of investing resource rents, $\dot{K}(t) = \left[F_R - f'(R)\right]R(t)$ enables the economy to follow a constant consumption path. Hence, by investing in reproducible capital the amount of economic depreciation (total Hotelling rent), we can prevent the economy from grinding to a halt as the resource stock is run down. This result depends crucially on the substitutability between reproducible capital and the natural resource, as well as no depreciation of reproducible capital.

National Accounting and Deforestation

We now turn our attention to how one might adjust NNP for deforestation, taking into account the change in land use and the non-marketed services that forests provide. A change in land use is essentially the consequence of one activity outbidding the current activity for the use of land. Hence, clearing would necessitate stock (or capital good) revaluation in the national accounts. In a world of perfect competition where property rights are well-established, land value typically increases as a result of the conversion of forest land to other uses, for example, agricultural, urban. The market value of land is just the present value of the benefits (rent) stream from the use of the land.

Two factors complicate these calculations. First, changing uses can degrade the quality of the land. Second, in an environment of weak property rights, the true scarcity price of the land may be undervalued. Since much of the services provided by forests are non-marketed and hence not valued (or at best, undervalued), the price of an area of forested land is "artificially" low. Hence, ill-defined property rights can accelerate deforestation beyond what is optimal by making it easy for an alternative land use to out-bid forest use of the land. We present Hartwick's (1992) treatment of deforestation in a national accounting framework.

Let $\overline{L}(t)$ be the total land area available at time t in the economy, for which there are only two uses, forest and agriculture. And let $L(t)$ be the area of land in agriculture. Then $\overline{L}(t) - L(t) = S$ is the area of forest land. At each date, $R(t)$ hectares of forest land is cleared to make way for agriculture. The cost of clearing R hectares is $f(R)$. A composite commodity "wheat" is produced using reproducible capital and agricultural land as inputs. The associated production function is $F(K,L)$. The stock of capital evolves according to

$\dot{K}(t) = F(K(t), L(t)) - C(t) - f(R)$. In addition to timber, forests provide direct services $G(\overline{L} - L)$ and indirect services $g(\overline{L} - L)$, which yield utility directly to the agent. For the sake of classification, let's take direct services to be those that are marketed and indirect as non-marketed services. $X(R)$ is the services provided by the timber from the cleared forest land.

The optimal growth problem's Hamiltonian is given by

$$\underset{c(t),\dot{K}(t)}{Max} \int_0^{\infty} e^{-\rho t} U(C, G(\overline{L} - L), g(\overline{L} - L), X(R))dt$$

s.t.

$$\dot{K}(t) = F(K(t)) - C(t) - f(R(t))$$
$$\dot{L}(t) = R(t)$$
$$\dot{S}(t) = -R(t)$$

The associated current-value Hamiltonian is

$$\begin{aligned} H(t) &= U(C, G(\overline{L} - L), g(\overline{L} - L), X(R)) \\ &+\lambda(t)[F(K, L) - C - f(R)] + \varphi(t)R - \phi(t)R \end{aligned}$$

First order conditions are

$$H_C = 0 \;\Rightarrow\; U_C = \lambda(t)$$

$$H_R = 0 \;\Rightarrow\; \frac{U_X X'(R)}{U_C} - f'(R) = -\frac{\varphi(t) - \phi(t)}{\lambda(t)}$$

Using a linear approximation of U(•) and dividing the current-value by U_C gives the result

$$\begin{aligned} \frac{H(t)}{U_C} &= C + \frac{U_G}{U_C}\frac{dG}{d(\overline{L} - L)}(\overline{L} - L) + \frac{U_g}{U_C}\frac{dg}{d(\overline{L} - L)}(\overline{L} - L) + \frac{U_X}{U_C X'(R) R} + \dot{K} \\ &- \left[\frac{U_X}{U_C} X'(R) - f'(R)\right] R \end{aligned}$$

or

$$\begin{aligned} NNP_{adj}(t) &= C + P_D(\overline{L} - L) + P_I(\overline{L} - L) + P_X R + \dot{K} - [P_X - f'(R)]R \\ &= C + P_D(\overline{L} - L) + P_I(\overline{L} - L) + \dot{K} + f'(R)R \end{aligned}$$

where $P_D \equiv \frac{U_G}{U_C} \frac{dG}{d(\bar{L} - L)}$ is the price of direct forest services, $P_I \equiv \frac{U_g}{U_C} \frac{dg}{d(\bar{L} - L)}$ the price of indirect forest services and $P_X \equiv \frac{U_X}{U_C} X'(R)$ the price of services provided by the timber from clearing forest land. The term *f′(R)R* represents the appreciation in land value from the conversion of forest land into more productive agriculture land.

φ(T) and ϕ(t) are the shadow prices of agricultural land and forest land respectively. To see that they are just the present value of the stream of benefits from a marginal unit of land (in its particular use), we look at the remaining first order conditions

$$-H_L = \dot{\varphi} - \rho\varphi \quad ==> \ \varphi(t) = \int_t^\infty e^{-\rho(v-t)} [U_C(v) . \ F_L(v)] \ dv$$

$$-H_S = \dot{\phi} - \rho\phi \quad ==> \ \phi(t) = \int_t^\infty e^{-\rho(v-t)} \left[U_G(v) \cdot \frac{dG(v)}{dS(v)} + U_G(v) \cdot \frac{dg(v)}{dS(v)} \right] dv$$

When adjusting historical NNP to take into account deforestation, we note that conventional NNP in Thailand is designed to include the value of new agricultural land converted from forest land as capital formation. It is measured in a term called "land improvement" which shows up as a real capital gain in NNP. Hence the adjustment we need to make, in addition to accounting for the non-marketed forest services, is a deduction for the value of land taken out of forests, $-\phi(t)R(t)$.

Extending for Land Degradation

Suppose agriculture results in land degradation, say soil quality degradation. The effect can be modelled in the following way. We include an index of soil quality,

$$\dot{A}(t) = bA(t) + \beta(Y(t)) - \delta F(K(t), A(t)L(t))$$

where b is the natural rate of recovery of the soil, $Y(t)$ is the amount of fertilizer used, which costs $h(Y)$, and $\beta(Y)$ is soil improvement due to the use of fertilizer. Agricultural activity causes degradation by a factor of δ.

The current-value Hamiltonian for this problem is

$$\begin{aligned} H(t) = U(C, G(\bar{L} - L), g(\bar{L} - L), X(R)) + \lambda(t)[F(K, AL) - C - f(R) - b(Y)] \\ + \varphi(t)R - \phi(t)R + \eta(t)[bA + \beta(Y) - \delta F(K, AL)] \end{aligned}$$

First order conditions imply $U_C = \lambda(t)$, $\frac{U_X X'(R)}{U_C} - f'(R) = -\frac{\varphi(t)-\phi(t)}{\lambda(t)}$

and $\frac{h'(Y)}{b'(Y)} = \frac{\eta(t)}{\lambda(t)}$

We end up with an adjusted NNP of

$$NNP_{adj} \equiv \frac{H(t)}{U_C} = C + P_D(\bar{L}-L) + P_I(\bar{L}-L) + P_X R + \dot{K} - \left[\frac{U_X X'(R)}{U_C} - f'(R)\right]R + \frac{h'(Y)}{\beta'(Y)}\dot{A}$$

The last term in the expression is the extra term we have to adjust for here. Since soil degradation takes place, $\dot{A} < 0$. $\frac{h'(Y)}{\beta'(Y)}$ is the marginal "wheat" cost per unit improvement in soil quality. Multiplied by $\dot{A}$, it is the economic depreciation borne by society as a result of the decline in soil quality. Note that it is not deforestation itself that causes soil degradation, it just puts it into a use that causes the degradation.

It is, however, not difficult to incorporate some of the off-site costs of soil and hydrological disturbances due to deforestation. Again, *A* is our index of land quality. A degradation in land quality can be expanded to include hydrological functions of the land as well as the nutrient levels in the soil. Hence, degraded land not only has lower levels of soil nutrients, it is also more susceptible to flooding and soil particle losses. In addition to the effect *A* has on production, a decline in *A* also imposes monetary costs on society, $z(\dot{A})$, in the form of homes destroyed by floods and damage to dams and reservoirs due to sedimentation. These are costs outside the productivity effects on agricultural land. Hence, our capital stock evolves according to

$$\dot{K} = F(K, AL) - C - f(R) - Y - z(\dot{A})$$

where *Y* is the amount of money spent improving land quality, for example, practicing conservation measures like flood prevention and building terraces.

The current value Hamiltonian to this problem is the following

$$H(t) = U(C, G(S), g(S), X(R)) + \lambda\big[F(K, AL) - C - f(R) - Y - z(bA + \beta(Y) - \delta F(K, AL))\big] + \varphi R - \phi R + \eta[bA + \beta(Y) - \delta F(K, AL)]$$

The foc's associated with *C* and *R* remain the same as before and the foc associated with *Y* is

$$\lambda\ [1+z'(A)\beta'(Y)]=\eta\beta(Y), \qquad \text{or} \qquad \frac{\eta}{\lambda}=\frac{1}{\beta'(Y)}+z'(A)$$

Adjusted NNP is thus

$$NNP_{adj}(t)=C+P_D(\overline{L}-L)+P_I(\overline{L}-L)+\dot{K}+f'(R)\,R+\left[\frac{1}{\beta'(Y)}+z'(\dot{A})\right]\dot{A}$$

A decline in land quality, whether in terms of nutrient loss or loss of hydrological functions, results in economic depreciation due to two effects. First, a direct effect on future production, the marginal cost of which is $\frac{1}{\beta'(Y)}$. And second, an indirect effect imposed by a reduction in current reproducible capital accumulation $\dot{K}$ by the amount $z(\dot{A})$ (the marginal cost of this is $z'(\dot{A})$), which in turn affects future production. This economic depreciation is given by the term $\left[\frac{1}{\beta'(Y)}+z'(\dot{A})\right]\dot{A}$.

Risk-Adjusted NNP

In this section, we consider an additional role for biodiversity as the “glue” that holds together the global ecosystem. This is related to the idea of preserving biodiversity as an insurance against changing global conditions and possible ecological collapse. Suppose biodiversity has a role in supporting the functioning of the world as we know it, then forests, obviously, form part of our global life-support system. Hence, as we clear forests (in particular, tropical rain forests that are said to house a higher degree of biodiversity than any other ecosystem we know), we are inducing biodiversity loss and increasing the risk of an ecological collapse at some future date. We extend our model to reflect this.

Say we run a risk of major ecological catastrophe that is directly related to biodiversity loss (deforestation). So as we deplete our stock of biodiversity (which we proxy with forest area), the probability of ecological collapse at date T increases with cumulative deforestation.

Let the states of the world be represented by $\overline{\Phi}$ and $\underline{\Phi}$, where $\underline{\Phi}$ represents ecological collapse. The probability of a switch from $\overline{\Phi}$ to $\underline{\Phi}$ in the interval (t_1,t_2) is

$$\int_{z(t_1)}^{z(t_2)} f(z)dz\,,$$

where $z(t) = \int_0^{\infty} R(s)ds$ (cumulative deforestation). Hence, the larger $z(t)$, the larger is the probability of an ecological collapse.

Production function is given by $Q(K(t), L(t), \overline{\Phi})$ and the cost of transforming R area of forest into agricultural land is $g(R)$. We simplify the problem by not considering other forest services.

State equations are given by:

$$\dot{K}(t) = Q(K(t),\ L(t), \overline{\Phi}\ ) - \ C(t)\ -\ g(R(t))$$

$$\dot{S}(t) = -R(t)$$

$$\dot{L}(t) =\ R(t)$$

with initial stocks being S_0 and K_0

Given the switch to $\underline{\Phi}$ at time T, $K(T)$ and $S(T)$ remains and the optimal certainty path of consumption thereon is $C^*(t)$.

We define discounted utility from the time of ecological collapse on as

$$W(K(T), S(T)) = \int_T^{\infty} e^{-\rho t} U(C^*(t))dt$$

So, our maximand for the optimal growth problem becomes

$$E\left\{\int_0^T U(C(t))e^{-\rho t}dt + W(K(T), S(T))\right\}$$

$$= \int_{z(0)}^{z(T)} f(z)\left\{\int_0^T U(C(t))e^{-\rho t}dt + W(K(T), S(T))e^{-\rho t}\right\}dz$$

$$= \int_o^{\infty} f(z(T))R(T)\left\{\int_o^t U(C(t))e^{-\rho t}dt + W(K(t), S(t))e^{-\rho t}\right\}dT$$

$$= \int_o^{\infty}\int_t^{\infty} f(z(v))R(v)U(C(t))e^{-\rho t}dvdt$$

$$+ \int_o^{\infty} W(K(T)S(T))e^{-\rho T} f(z(T))R(T)dT$$

$$= \int_o^{\infty} F(z(t))U(C(t))e^{-\rho t}dt + \int_o^{\infty} \rho W(K(T), S(T)) f(z(t))R_t e^{-\rho t}dt$$

where $F(z(t)) = \int_t^{\infty} f(z(v))R(v)dv$ is the probability that collapse occurs after date t.

The current value Hamiltonian associated with this problem is

$$H(t) = U(C(t))F(z(t)) + \rho W(K(t), S(t) f(z(t))R(t)$$
$$+ \lambda\left[Q(K(t), L(t), \overline{\Phi}) - C(t) - g(R(t))\right] + \varphi R(t) - \phi(t)R(t)$$

First-order conditions are

$$H_C = 0 \Rightarrow F(z)U_C = \lambda$$

$$H_R = o \Rightarrow \rho Wf(z) + \lambda g_R = -(\varphi - \phi)$$

So we have

$$-\frac{\varphi(t) - \phi(t)}{\lambda(t)} = g_R + \frac{f(z)}{F(z)}\rho\frac{W}{U_c}$$

$$= g_R + \frac{f(z)R}{F(z)}\rho\frac{W}{RU_c} \quad \text{where} \quad \frac{FR}{F} \text{ is the hazard rate.}$$

(i) NNP (Before collapse):

$$\frac{H}{F(z(t))U_C} = \frac{U(c)}{U_C} + \rho\frac{W}{U_C}\frac{fR(t)}{F} + \dot{K} - [g_R + X]R(t)$$

where $X = \rho\frac{W}{U_C}\frac{fR}{F}\frac{1}{R}$

or $\frac{H(t)}{U_C} = F(z(t))\left[C + \dot{K} - g_R R\right]$

So, prior to an ecological collapse, NNP is just the NNP we have already encountered, but adjusted for the probability that collapse has not occurred.

(ii) NNP (After collapse):

At collapse, $F(z(t))$ drops to 0 and $f.R(t)$ rises to 1

H (t) = $\rho \ W(t)$

With this, we conclude the theoretical cases of adjustments that we may, with sufficient data, make to NNP to allow for economic depreciation associated with the use of a nation's forests.

III. NATURAL RESOURCE ACCOUNTING CASE STUDIES

Sadoff (1993) calculates the national account adjustments for Thailand's forests for the period 1970-90 and uses natural resource accounting to evaluate Thailand's forest management system. Her adjustments follow most natural resource accounting methodologies in imputing only the commercial losses associated with forest depletion. In a situation of perfect property rights, this approach correctly measures the depreciation associated with deforestation and the changing land use. Recall that, abstracting from other forest services and assuming markets are efficient,

$$NNP_{adj}(t) = C + P_X . R + \dot{K} - [P_X - f'(R)] R$$

Sadoff calculates the entire land revaluation term without allowing for the fact that the gains from new agricultural land is entered as part of conventional national accounts. She justifies this by indicating that "land improvement," while entering Thailand's GDP as investment, fails to capture the majority of forest land cleared. "New land," the subcategory in Thailand's land improvement measure, is complied with according to the issuance of full land titles (NS3s) in each accounting period. The highly restrictive NS3 titles are granted for privately owned lands by the Department of Land (DOL). Currently, only 15 percent of privately owned lands, the majority of which is urban, hold NS3 titles. In addition, the DOL requires five years of prior ownership before the titles are granted. Sadoff concludes that these restrictions suggest that only a small fraction of converted forest land is ever recorded in Thailand's GDP as land improvement, and that which is recorded is done so at least five years after deforestation has occurred.

Sadoff calculates the adjustment term via two different approaches which she calls the "deprecation method" and the "user-cost method." The "depreciation" approach uses net price multiplied by forest area cleared to arrive at economic depreciation. This term is just Hotelling rent and is simply the net price method prescribed by Hartwick's conceptual framework.

The "user-cost" approach, derived by El Serafy (1989) separates the use cost from Hicksian (sustainable) income. The use cost represents the portion of current income that must be set aside for reinvestment in order to maintain an income stream into perpetuity. Hartwick and Hageman (1993) have demonstrated that the theoretical basis of El Serafy's method is equivalent to that of the net price method. They also showed, however, that due to simplifying assumptions required to implement the user-cost method, it yields correct estimates only when total resource rent is constant over time.

In the case of renewable resources, El Serafy suggests that future income streams can be maintained by replacing the resources removed in each period. Hence, this replacement cost can be charged against current income as a user cost. This is the approach adopted by Sadoff in calculating the user costs associated with the depletion of Thailand's forest resources.

The "depreciation" approach made use of stumpage value, calculated from world export log prices by subtracting the costs of extraction, transportation and milling, for its calculation of net price. Note that this estimation is based on average, not marginal, costs which tends to overstate the depreciation deductions because average costs tend to be lower than marginal costs in extractive industries.

A comparison of Sadoff's results show that adjustments calculated via the "depreciation" approach consistently exceeds the figures obtained from the user-cost approach.

Our study differs from Sadoff's in that we attempt to value some of the important forest functions that are unvalued or undervalued by markets. We do not impute only the commercial losses associated with forest depletion but also the losses of non-marketed forest service. Hence, we impute the value of forest land by estimating the present value of the stream of rents from the forest land.

In a WRI study of Indonesia, Repetto *et al*. (1989) used average net price to calculate depreciation allowances for timber as well as non-renewable resources (petroleum and soil) for the period 1971-84. They found that the aggregate resource depreciation was equivalent to about a quarter of GDP. They also calculated a partial measure of net investment by subtracting the resource consumption allowance from gross capital formation.[2] They found that net investment was negative in two years, but aggregated over the entire period it was positive. This is an encouraging result, but one cannot be sure that Indonesia's total capital stock increased without making the necessary deductions for the depreciation of reproducible human-made capital.

In the study on Costa Rica, Repetto *et al.* (1991) calculated a more complete measure of net investment by deducting both capital and resource consumption allowances. In addition to allowances for timber and soils, they included an allowance for fisheries resources. They excluded petroleum because Costa Rica is not a producer. They found that net investment rose rapidly during the 1970s but stagnated during the 1980s, when a high rate of deforestation increased the resource consumption allowance. However, net investment was positive for every year of the period considered.

Two studies by the United Nations and World Bank were conducted in Papua New Guinea. The main purposes of these studies were to apply the proposed changes in the UN System of National Accounts, to developing countries and to test the feasibility of attempting integrated accounting. As a consequence, no effort was made to collect data firsthand. Rather, the data were obtained from existing institutions. In Papua New Guinea, Bartelmus *et al.* (1993) estimated depreciation allowances for mineral resources over the period

[2] Data on capital consumption allowance were apparently not available.

1956-90. They did not include forest and other renewable resources due to data limitations. They found that the net human-made capital accumulation during those years exceeded the depletion of mineral resources. It is hard to conclude that Papua New Guinea is thus depleting its natural resources in a sustainable manner since the depreciation of other resources needs to be included. In Mexico, van Tongeren *et al.* (1993) estimated depreciation allowances for the use of oil, forest and environmental resources (air, water and land) in the year 1989. They found that net investment was positive in the only year analyzed after accounting for both human-made capital and natural capital depreciation.

Note that all of the above studies impute only the commercial costs of resource depletion.

Many other studies attempt to value forests inclusive of the non-marketed services they provide. These studies are not done on a national accounting framework and are basically natural resource valuation exercises.

IV. CONCLUSION

We have used the optimal growth model to study the characteristics of a "green" national accounting framework. The advantage of a theoretical framework is in providing insights into the nature of the shadow prices we need and how we should treat different types of natural assets. Here are some of the practical issues associated with the construction of the "green" national accounts advocated by this approach.

A subject that has been debated in the literature on natural resource accounting is the treatment of defensive expenditures. In our model with environmental degradation, current defensive expenditures against damages to the flow of environmental amenities (the variable $z(\dot{A})$ in the model) shows up in NNP as a decline in reproducible capital accumulation. Consider, for example, the labour that is spent on cleaning up environmental pollution. Such defensive expenditures, however, should not be deducted from national accounts since, if the economy is in full employment, the hiring of labour in the clean-up industry will be offset by a reduction in production somewhere else in the economy. If the economy is not in full employment, the shadow price of labour, and hence the wage bill, will be zero in any case. Notice that the adjustment term is $z'(\dot{A})\dot{A}$ which reflects the impact of the reduced capital accumulation on future production. Expenditures which are aimed at enhancing environmental capital (the variable Y in the same model) find expression in the value that is imputed to changes in the environmental resource stock.

Next, consider the interaction between the economy of interest and the rest of the world. Suppose the economy is subject to transboundary pollution, and can import or export pollution. We need to turn to the fundamental question of whose welfare should be considered.

Suppose the objective is to create an index measuring the impact on global well-being from the activities in one country. Then we should deduct the environmental damage the economy's projects give rise to abroad. If all countries based their accounts on this criterion, all accounts would be consistent and thus could be summed to give global welfare.

Perhaps the approach more appealing to an individual country's policy-makers would be to consider all changes that affect the country but limit the adjustments to NNP to those consequences that apply to the citizens in the home country, effectively, the costs they bear from the use of natural capital. In this case, we would want to include in our welfare measure only the part of transboundary environmental damages, either generated domestically or in other countries, that directly affect the economy. Again, so long as all countries apply the same rule, we have a consistent system that can be summed to obtain global welfare.

Finally, our adjusted NNP allows for the economic depreciation of natural resource stocks, which is net price times the change in stock. We are interested in the value of the change in stock, and not the change in the value of the stock. That is, we do not consider anticipated capital gains or losses associated with price changes.

REFERENCES

Adger, N. and M. Whitby (1991), "Accounting for the Impact of Agriculture and Forestry on Environmental Quality, "*European Economic Review* 35, 629-641.

Asian Development Bank (1996), *Economic Evaluation of Environmental Impacts: A Workbook, Parts I and II* (Manila: Environment Division, Asian Development Bank, ADB).

Aylward, B.A. (1991*), The Economic Value of Ecosystems: 3-Biological Diversity*, LEEC gatekeeper Series GK91-03 *(*London: International Institute for Environment and Development, IIED).

———— (1993), *The Economic Value of Pharmaceutical Prospecting and its Role in Biodiversity Conservation*, LEEC Discussion Paper DP93-05 (London: International Institute for Environment and Development, IIED).

Aylward, B.A. and E.B. Barbier (1992), *What is Biodiversity Worth to a Developing Country? Capturing the Pharmaceutical Value of Species Information*, LEEC Discussion Paper DP 92-05 (London: International Institute for Environment and Development, IIED).

Balick, M.J., and R. Mendelsohn (1992), "Assessing the Economic Value of Traditional Medicines from Tropical Rain Forests," *Conservation Biology* 6(1), 128-130.

Barbier, E.B. (1993), "Tropical Wetland Values and Environmental Functions," in A. Perrings *et. al.* (eds.), *Biodiversity Conservation* (The Netherlands: Kluwer Academic Publishers).

Bartelmus, P., E. Lutz and S. Schweinfest (1993), "Integrated Environmental and Economic Accounting: A Case Study for Papua New Guinea," in E. Lutz (ed.), *Toward Improved Accounting for the Environment* (Washington DC: The World Bank).

Boonpragob, K. (1996), *Thailand's Role in a Global Context,* TEI 1996 Annual Conference, "Linking Local Solutions to Global Needs: Thailand's Environmental Agenda in the 21st Century" (Bangkok: TEI).

Bruijnzeel, L.A. *(1990), Hydrology of Moist Tropical Forests and Effects of Conversion: A State of Knowledge Review (*Amsterdam: Netherlands

Committee for the International Hydrological Programme of UNESCO).
Chomitz, K.M. and K. Kumari (1996), *The Domestic Benefits of Tropical Forests: A Critical Review Emphasizing Hydrological Functions*, Policy Research Working Paper No. 1601 (Washington DC: The World Bank).
Dasgupta, P., B. Kriström and K.G. Mäler (1995), "Current Issues in Resource Accounting," in P.O. Johansson, B. Kriström and K.G. Mäler, (eds.), *Current Issues in Environmental Economics* (Manchester: Manchester University Press).
Dasgupta, P. and K.G. Mäler (1990), *The Environment and Emerging Development Issues*, Development Economics Research Programme Paper No. 28 (London: London School of Economics).
De Beer, J.H. and M.J. McDermott (1989), *The Economic Value of Non-Timber Forest Products in Southeast Asia, With Emphasis in Indonesia, Malaysia and Thailand* (Amsterdam: IUCN).
El Serafy, S. (1989), "The Proper Calculation of Income from Depleting Natural Resources" in J.A. Yusuf, S. El Serafy and E. Lutz (eds.), *Environmental Accounting for Sustainable Development (*Washington DC: The World Bank).
Faeth, Cort and Livernash (1994), *Evaluating the Carbon Sequestration Benefits of Forestry Projects in Less Developed Countries* (Washington, DC: World Resources Institute ,WRI).
Godoy R., R. Lubowski and A. Markandya (1993), "A Method for the Economic Valuation of Non-Timber Tropical Forest Products," *Economic Botany*, *47 (3*), 220-233.
Grimes, A., S. Loomis, P. Jahnige, M. Murngam, K. Onthank, R. Alarcón, W.P. Cuenca, C.C. Martinez, D. Neill, M. Balick, B. Benet and R. Mendelsohn (1994), "Valuing the Rain Forest: The Economic Value of Non-timber Forest Products in Ecuador," *Ambio* 23 (7).
Hamilton, L.S. (1988), "Forestry and Watershed Management, " in J. Ives and D.C. Pitt (eds.), *Deforestation: Social Dynamics in Watersheds and Mountain Ecosystems*, European Year of the Environment Series, (London: Routledge).
Hamilton, L.S. and A.J. Pearce (1988), "Soil and Water Impacts of Deforestation," in J. Ives and D.C. Pitt (eds.), *Deforestation: Social Dynamics in Watersheds and Mountain Ecosystems*, European Year of the Environment Series (London: Routledge).
Hartwick, J.M. (1990), "Natural Resources, National Accounting, and Economic Depreciation," *Journal of Public Economics* 43 (3), 291-305.
——— (1993),"Notes on Economic Depreciation of National Resource Stocks and National Accounting," in A. Franz and C. Stahmer (eds.), *Approaches to Environmental Accounting: Proceedings of the IARIW*

Conference on Environmental Accounting, (Heidelberg: Physica-Verlag).

——— (1993), "Forestry Economics, Deforestation and National Accounting" in E. Lutz (ed.), *Toward Improved Accounting for the Environment* (Washington, DC: The World Bank).

Hartwick, J.M. and A. Hageman (1993), "Economic Depreciation of Mineral Stocks and the Contribution of El Serafy," in E. Lutz (ed.), *Toward Improved Accounting for the Environment* (Washington, DC: The World Bank).

Hartwick, J.M. and N.D. Olewiler (1986), *The Economics of Natural Resource Use* (New York: Harper & Row Publishers).

Hotelling, H. (1931), "The Economics of Exhaustible Resources," *Journal of Political Economy* 39, 137-175.

Kramer, R.A., N. Sharma and M. Munasinghe (1995), *Valuing Tropical Forests: Methodology and Case Study of Madagascar*, World Bank Environmental Paper No. 13 (Washington DC: The World Bank).

Lonergan, S., P. Dearden and J. Ruiten (1994), *An Ecological Economics Study of the Chao Phraya River Basin, Thailand* (Victoria, BC: Centre for Sustainable Regional Development).

Magrath, W.B., C.M. Peters, N. Kishor and P. Kishor (1995), "The Economic Supply of Biodiversity in West Kalimantan: Prelimary Results," in S. Shen and A. Contresras-Hermosilla (eds.), *Environmental and Economic Issues in Forestry: Selected Case Studies in Asia*, World Bank Technical Paper No. 281 (Washington, DC: The World Bank).

McNeely, J.A. (1988), *Economics and Biological Diversity: Developing and Using Economic Incentives to Conserve Biological Resources* (Switzerland: International Union for Conservation of Nature and Natural Resources).

Munasinghe, M. and E. Lutz (1993), "Environmental Economics and Valuation in Development Decisionmaking," in M. Munasinghe (ed.), *Environmental Economics and Natural Resource Management in Developing Countries*, Committee of International Development Institutions on the Environment (CIDIE), (Washington DC: The World Bank).

Norse, D. and S. Reshma (1993), "National Economic Cost of Soil Erosion in Zimbabwe" in M. Munasinghe, (ed.), *Environmental Economics and Natural Resource Management in Developing Countries*, Committee of International Development Institutions on the Environment (CIDIE) (Washington DC: The World Bank).

Panayotou, T. and C. Parasuk (1990), "Land and Forest: Projecting Demand and Managing Encroachment," TDRI Year-end Conference (Bangkok: TDRI).

Pearce, D. (1994), *Global Environmental Value and the Tropical Forests: Demonstration and Capture (*London: Centre for Social and Economic Research on the Global Environment).

Pearce, D. and D. Moran (1994), *The Economic Value of Biodiversity (*London: The World Conservation Union, IUCN).

Pearce, D., D. Whittington, S. Georgiou and D. Moran (1994), *Economic Values and the Environment in the Developing World,* report to UNEP (London and Chapel Hill: CSERGE, University College London, University of East Anglia and University of North Carolina at Chapel Hill).

Reid, W.V., C.V. Barber and A. La Vina (1995*),* "Translating Genetic Resource Rights into Sustainable Development: Gene Co-ops, the Biotrade, and Lessons from the Philippines*,"* *Plant Genetic Resources Newsletter*, March 27, 1995.

Reid, W.V., J.A. McNeely, D.B. Tunstall, D.A. Bryant and M. Winoghrad (1993), *Biodiversity Indicators for Policy-Makers*, IUCN (Washington DC: World Resources Institute, WRI).

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

Repetto, R., W. Cruz, R. Solorzano, R. De Camino, R. Woodward, J. Tosi, V. Watson, A. Vasquez, C. Villabos and J. Jimenexd (1991), *Accounts Overdue: Natural Resource Accounting in Costa Rica* (Washington, DC: World Resources Institute, WRI).

Sadoff, C.W. (1991), "The Value of Thailand's Forests," *TDRI Quarterly Review* 6, 19-24.

——————— (1992), "The Importance of Accepting for Natural Resources and the Environment," *TDRI Quarterly Review* 7, 18-24.

——————— (1993), *Natural Resource Accepting: A Case Study of Thailand's Forest Management*, Ph.D. dissertation (Berkeley: University of California).

Solow, R.M. (1986), "On the Intergenerational Allocation of Natural Resources," *Scandinavian Journal of Economics,* 88 (2), 141-149.

Simpson, D., R. Sedjo and J. Reid (1994), *Valuing Biodiversity: An Application to Genetic Prospecting,* Resources for the Future Discussion Paper 94-20.

Tisdale, P. (1996), *Natural Resource Accounting: A Case Study of Natural Gas in Thailand* (Bangkok: TDRI).

Thailand Development Research Institute (TDRI) and Harvard Institute for International Development (HIID) (1995), *Green Finance: A Case Study of Khai Yai* (Bangkok: TDRI).

Thailand Development Research Institute (TDRI) and Thailand Environment Institute (TEI) (1993), *Preparation of a National Strategy on Global Climate Change: Thailand* (Bangkok: TDRI).

Tobias, D. and R. Mendelsohn (1991), "Valuing Ecotourism in a Topical Rain-Forest Reserve," *Ambio* 20 (2), 91-93.

Van Tongeren, J., S. Schweinfest, E. Lutz, M. Gomez Luna and G. Martin (1993), "Integrated Environmental and Economic Accounting: A Case Study for Mexico," in E. Lutz (ed.), *Toward Improved Accounting for the Environment* (Washington, DC: The World Bank).

Vincent, J.R. and M. Kaosa-ard (1995), *The Economics of Watershed Management: A Case Study of Mae Taeng* (Bangkok: TDRI and HIID).

Weitzman, M.L. (1976), "On the Welfare Significance of National Product in a Dynamic Economy," *Quarterly Journal of Economics* 90 (1), 156-162.

World Conservation Monitoring Centre (WCMC) (1992), *Global Biodiversity: Status of the Earth's Living Resources* (London: Chapman and Hall).