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Natural Resources, National Accounting and Economic Depreciation

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Abstract

The current value Hamiltonian in an aggregate optimal growth problem with heterogeneous capital stocks including exhaustible, renewable and environmental stocks is the NNP function. Routine substitutions reveal that the using up of natural resource stocks is representable as easy-to-interpret economic depreciation magnitudes. We obtain true NNP inclusive of natural resource stock diminution.

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Introduction

Solow [1986] extended explicitly Weitzman's [1976] capital theoretic treatment of the national accounts to incorporate exhaustible resources as distinct capital goods. Here we extend the approach to deal with renewable resources, and environmental capital (pollution abatement). The message is: GNP incorporates priced resource input flows and these flows from capital stocks should be "off-set" by deductions from GNP to incorporate declines (or possibly increases) in natural resource stocks. There is explicit "economic depreciation" of natural resource capital which should be deducted from GNP to arrive at a correct estimate of NNP (net national product). As Samuelson [1961] and Weitzman [1976] contend, NNP is the best welfare measure we have under standard national income accounting procedures. The familiar "capital consumption allowance" separating GNP and NNP should be expanded to incorporate the additional "capital consumption" each year accounted for by the decline (or growth) of natural resource stocks.[1] This is not a proposal for ad hoc extensive new "nettings-out" from GNP. It only makes economic sense to deduct economic depreciation from GNP for those stocks whose flows are priced appropriately in GNP. For example, airsheds and watersheds are stocks whose flows of services "enter" the economy but are generally un- or underpriced. Thus the correct approach would be to re-price the environmental services by appropriate scarcity or shadow prices and revise

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[1] Usher [1981, pp. 114-115], Ward [1982], Stauffer [1985], El Serafy [1981] and Eisner [1988; Appendix B] have argued for deductions from GNP to take account of exhaustible resources used up.

GNP upward. Then any annual declines (increases) in the corresponding stocks should be valued and netted out (added to) of GNP to obtain NNP. We elaborate on this argument below.

Our approach is simple to summarize. Weitzman [1976] and others noted that the current value Hamiltonian in aggregate neoclassical growth theory is, given minor re-normalization, an economy's NNP. Parts of NNP are net increases in the value of produced capital goods (net investment). But when neo-classical growth incorporates natural capital, net "investment" includes the economic depreciation (value of declines) in natural resource capital goods. The steps of dynamic optimization yield market or scarcity values for all changes in capital stocks. Thus we end up with procedures for arriving at the correct measure of NNP, a measure which incorporates the current loss in value of natural resource stocks due to use for exhaustible resources and, roughly speaking, over-use for renewable and environmental resources.

We will take up each type of natural resource capital separately since the accounting prescription for each is slightly different in practice, though the same in principle.

NNP and the Economic Depreciation of Exhaustible Resources

Consider optimal growth in an economy in which $\int_0^\infty U(C)e^{-\rho t}dt$ is being maximized subject to $\dot{K} = F(K, L, R) - C - f(R, S)$ and $\dot{S} = -R$ where C is aggregate consumption, $U(\cdot)$ is the aggregate utility function, ρ is the social discount rate, K is the stock of produced capital, L is the current labor force $\left(L(t) = L_0e^{nt}\right.$ where n is the rate of growth of the labor force$\left.\right)$, R is the current flow from stock S of an exhaustible resource (pool of oil?), F(K, L, R) is the aggregate production function for "manufactured" output, and f( ) is the current cost of exhaustible resource extraction, defined in terms of the composite produced good. f_R is the marginal cost of producing R from the stock S. The current value Hamiltonian for this maximization problem is

$$H(t) = U(C) + \phi(t)\left[F(K, L, R) - C - f(R, S)\right] + \varphi(t)[-R]$$

where $\phi(t)$ and $\psi(t)$ are co-state variables. The canonical equations for optimization are

$$\text{(i)} \quad \frac{\partial H}{\partial C} = 0 \quad \text{or} \quad U_C = \phi(t)$$

$$\frac{\partial H}{\partial R} = 0 \quad \text{or} \quad \phi\left[F_R - f_R\right] = \psi$$

$$\text{(ii)} \quad \dot{\phi}(t) = \rho\phi(t) - \frac{\partial H}{\partial K} \quad \text{or} \quad \phi\left[\rho - F_K\right] = \dot{U}_C$$

$$\dot{\psi}(t) = \rho\psi(t) - \frac{\partial H}{\partial S} \quad \text{or} \quad f_S + \rho\psi = \dot{\psi}$$

$$\text{and} \quad \text{(iii)} \quad \frac{\partial H}{\partial \phi} = \dot{K} \quad \text{or} \quad \dot{K} = F(K, L, R) - C - f(R, S)$$

$$\frac{\partial H}{\partial \psi} = \dot{S} \quad \text{or} \quad \dot{S} = -R$$

Let us use a linear approximation $U(C) = U_C \cdot C$ and divide the revised Hamiltonian by U_C $(=\phi(t))$. Then we have the "dollar-value" NNP function

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

$$= C + \dot{K} - \left[F_R - f_R\right]R$$

This indicates that current "Hotelling Rents", namely $[F_R - f_R]R$, should be netted out of GNP to arrive at NNP. Note that marginal product, F_R, is the market price of exhaustible resource flows and f_R is the <u>marginal cost of extraction</u>. This approach appears in Solow [1986] and the netting out rule is derived differently in Hartwick [1989]. A partial equilibrium derivation of the result: economic depreciation of exhaustible resources equals rent is presented in Hartwick and Lindsey [1989] and extensions to resource exploring-extracting firms are in Hartwick [1989a].[2] Of interest in our derivation above is that shifts in extraction costs, f(R, S) via changes in stock size do not enter into the formula for economic depreciation. This contrasts with the partial equilibrium results reported in Hartwick and Lindsey [1989]. We have not incorporated exploration activity which complicates matters because discovery precedes extraction. See Hartwick [1989a].

NNP and the Economic Depreciation of Renewable Resources

Consider now an economy with two consumer goods, a composite C and say fish, E. Then the utility of current aggregate consumption is U(C, E) with linear approximation $U_C \cdot C + U_E \cdot E$. Let fishing costs, in terms of the produced composite commodity be f(E, Z) where Z is the stock of fish and E is the current harvest. Then $\dot{K} = F(K, L) - C - f(E, Z)$ and $\dot{Z} = g(Z) - E$ where $F(\cdot)$ is currently produced composite commodity and g(S) is the natural growth in the stock. The current value Hamiltonian is now

$$H(t) = U(C, E) + \phi(t) \cdot \left[F(K, L) - C - f(E, Z)\right] + \psi(t) \cdot \left[g(Z) - E\right]$$

This can be written, in "dollar values" as

$$\frac{H(t)}{U_C} = C + \frac{U_E}{U_C} \cdot E + \frac{\phi(t)}{U_C} \dot{K} + \frac{\psi(t)}{U_C} \dot{Z}$$

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2 Solody [1980] grappled with the problem of netting out exhaustible resources used up from GNP when new resource discoveries were significant.

Using the canonical equations, we observe $U_C = \phi(t)$ and

$\psi(t)/U_C = \left\{[U_E/U_C] - f_E\right\}\dot{Z}$ or that the NNP function is

$$\frac{H(t)}{U_C} = C + \frac{U_E}{U_C} \cdot E + \dot{K} + \left[\frac{U_E}{U_C} - f_E\right]\dot{Z}$$

where U_E/U_C is the market price of a unit of fish in a competitive world and f_E is the <u>marginal cost</u> of fishing for E and $\dot{Z}$ is the current net change in the stock of fish. In a steady state, $\dot{Z}$ would be zero. In a growing economy, $\dot{Z}$ will likely be negative. It is the term $\left[\frac{U_E}{U_C} - f_E\right]\dot{Z}$ which is formally defined as economic depreciation when $\dot{Z} < 0$ and it is this term which should be netted out of GNP to arrive at NNP. An analysis quite similar to the above is Hartwick [1978].

We took for granted in the approach above that the economy comprised price taking competitive firms with clear property rights on inputs and outputs. As Gordon [1954] and others have emphasized, property rights failures for fish stocks (the common property problem) appear common. In this case we would expect excess inputs in fishing activity relative to efficient (perfect property rights) levels. Measured GNP would be somewhat less than "ideal" GNP given inefficient input levels. Rates of change in stocks would also presumably be altered by property rights failures. In brief then to correctly translate the above approach into national accounting procedures, given property right failures, extensive adjustments are required to move an observed second best pattern to an amended first best. Alternatively the complete second best problem should be analyzed, compared with the first best outcome, and appropriate adjustments made in the observed data, collected under the second best scenario. This is the well-known problem of translating observed prices in a distorted economy into basic scarcity prices (a particular problem in shadow pricing). We of course are not implying that such "translations" are easy to carry out or that the whole problem of distortions should be glossed over in national accounting. Rather we are presenting a set of procedures, valid under "competitive" conditions, but which require adjustments for economies with distortions. The problem of property rights failures is acute with environmental capital goods such as airsheds and watersheds. We turn to these capital goods now.

NNP and the Economic Depreciation of Environmental Capital

We will treat the volume of pollution X, a stock concept, as an input into production. For given inputs K and L, more pollution will imply less output in F(K, L, X).[3] In addition the production of this composite output adds to pollution or results in a positive $\dot{X}$. Net pollution increments are $\dot{X} = -bX + \gamma F(K, L, X)$ where in the absence of production (a positive F( )), $\dot{X} = -bX$ or pollution "evaporates" at rate b by natural environmental stock regeneration. γ is a parameter linking produced output to increments in pollution. The corresponding planning problem has a single control variable C and two state variables, namely K and X. The current value Hamiltonian is

$$H(t) = U(C) + \phi\cdot\left[F(K, L, X) - C\right] + \psi\cdot\left[-bX + \gamma F(K, L, X)\right]$$

once again $U_C = \phi$ but now $\psi/U_C = \left[\dfrac{\dfrac{-\dot{U}_C}{U_C} + \rho - F_K}{\gamma F_K}\right] \equiv V$. Then the "dollar-value" Hamiltonian becomes

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[3] Martin [1986] has a detailed analysis of the complications arising from having a bad in the production function. Isoquants have unusual properties.

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

where $V \cdot \dot{X}$ is the economic depreciation of environmental capital, evaluated in pollution units, rather than in units of environmental capital, per se. In the absence of pollution $V = 0$ because the numerator of V is zero. The numerator is in units of rate of return and F_K is the rate of return to capital in this polluted economy. Thus the numerator is a wedge in the rate of return and the denominator is the rate of return weighted by parameter γ. Thus the net rental, V, on a unit of pollution stock X is represented by a percentage wedge in the rate of return to produced capital K, namely F_K. Recall that co-state variables represent $\partial J(t)/\partial \alpha$ where α is a state variable and J(t) is the value of the optimal program from t to the end of the program. Thus $\psi(t) = \partial J(t)/\partial X(t) < 0$ since a larger stock of X reduces the value of the program. $\psi(t)$ is in units of utility and $\psi(t)/U_C$ is the same concept, except in units of the composite produced good.

In the above formulation, pollution was only controlled indirectly via the output decision of producers. More output caused more pollution of stock size X and more pollution retarded production in the sense that the same amounts of K and L produce less output for higher levels of X. X was, formally speaking, a state variable and there was no control variable corresponding to or acting directly on X as there was in our analysis above of exhaustible resources and renewable resources. There we observed that fairly straightforward rentals corresponded with economic depreciation, static price minus marginal cost entities. With environmental capital our economic depreciation term involved rates of return rather than prices minus marginal cost. Suppose we reformulate the model by introducing a pollution abatement control. Might we not then observe economic depreciation in a price minus marginal cost form? Yes, we will. We introduce abatement costs f(b) as a debit from the produced composite output. A higher value of b implies more rapid cleansing of stock X per unit time. The rate of reduction of X is sped up for larger b.[4] Our current value Hamiltonian becomes

$$H(t) = U(C) + \phi(t)\cdot\left[F(K,\ L,\ X) - C - f(b)\right] + \psi(t)\cdot\left[-bX + \gamma F(k,\ L,\ X)\right]$$

where C and b are now control variables. From $\partial H/\partial C = 0$ we obtain $U_C = \phi$ and $\partial H/\partial b = 0$ we obtain $-f'\phi = \psi X$. Then $\frac{\psi}{U_C} = \frac{-f'}{X} < 0$ and economic depreciation $\frac{\psi}{U_C}\dot{X} = \frac{-f'\dot{X}}{X}$ where f' is the marginal cost of increasing the rate of natural abatement by investment in abatement "capital", namely b. Note $\frac{df}{db}\frac{1}{X}$ is the extra composite commodity foregone, namely df which achieves extra abatement Xdb given the current stock of pollution X. It can be written $\Delta f/\Delta X$, a marginal cost of reducing X by investing some of the composite commodity in b, abatement "capital". To achieve reduction $\dot{X}$, the amount of composite commodity used up is, to a linear approximation, $\frac{\Delta f}{\Delta X}\dot{X}\left(\equiv \frac{f'\dot{X}}{X}\right)$. This economic depreciation term now resembles those derived above for the cases of exhaustible and renewable resources in the sense that it is a flow or change of stock ($\dot{X}$) multiplied by a marginal entity, expressed in units of the composite commodity. This result provides a capital theoretic rationale for deducting current pollution control expenditures from GNP to arrive at an NNP figure (see for example Bartelmus, Stahmer, and van Tongeren [1989]). Note however that pollution control costs are expressed in abatement $\dot{X}$ multiplied by the marginal cost of abating a unit of stock X. This is very different

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4 In a companion piece (Hartwick [1990]) we let human intervention "abate" pollution via the parameter γ rather than b. The results are qualitatively the same.

from using current resources expended in pollution control. This latter has been suggested by many people (e.g., Peskin [1976]. Recall that Nordhous and Tobin [1972, p. 49] netted out environmental degradation arising from pollution in an ad hoc fashion.). If $\dot{X} < 0$ or pollution declines then economic depreciation or $\frac{-f'\dot{X}}{X}$ becomes positive, representing an investment or capital appreciation, where the capital here is the stock of <u>clean</u> environmental capital.

<u>Disutility of Pollution</u>

A persuasive argument for not putting pollution in the utility function as in U(C, X) is made by Usher [1981]. His argument can be labelled the sunshine problem. It does not make sense to put sunshine in U( ) or the love of God, etc. as long as these stocks are <u>unchanging</u>. Similarly with the stock of pollution. But it does seem reasonable to assert that people are worse off if X increases or better off if X declines. This then is an argument for introducing changes in X into U if we consider that there are direct consumption or utility effects of pollution in addition to the deleterious effects of pollution on production. Suppose then, we revise our U(C) above to incorporate changes in the pollution stock, $\dot{X} = -bX + \gamma F(K, L, X)$. Then our current value Hamiltonian is

$$H(t) = U\big(C,\ \gamma F(K,L,X)-bX\big) + \phi(t)\big[F(K,L,X)-C-f(b)\big] + \psi(t)\cdot\big[-bX+\gamma F(K,L,X)\big]$$

Relations $\frac{\partial H}{\partial C} = 0$ and $\frac{\partial H}{\partial b} = 0$ yield $\frac{\psi}{U_C} = \frac{-U_{\dot{X}}}{U_C} - \frac{f'}{X}$ where $-U_{\dot{X}}/U_C$ is the price of pollution increments, a positive number since $U_{\dot{X}} < 0$ for $\dot{X} > 0$ and $\frac{f'}{X} \equiv \frac{\Delta f}{\Delta X} > 0$ as we noted above. Thus $\frac{\psi}{U_C}$ is the price of extra pollution minus the marginal cost of extra pollution and this rent will be negative since

$\psi(t) < 0$. That is $\frac{f'}{X} + \frac{U_{\dot{X}}}{U_C} > 0$ and economic depreciation is

$\frac{\psi(t)}{\phi(t)}\dot{X} \equiv -\left[\frac{U_{\dot{X}}}{U_C} + \frac{f'}{X}\right]\dot{X} < 0$ for $\dot{X} > 0$, which should be netted out of GNP to obtain NNP. Because X is a capital bad (as opposed to a capital good) our result is symmetric to our results for exhaustible and renewable resources, except for a sign change. Earlier economic depreciation was $+[p-mc]\dot{\alpha}$ where α was a capital good, $\dot{\alpha}$ was negative, and p-mc was a positive rent per unit of stock reduction. Immediately above we have $+[p-mc]\dot{X}$ where $\dot{X}$ is positive and [p-mc] is negative since X (pollution stock is a bad).

In the above analysis X and $\dot{X}$ entered directly into the large intertemporal optimization problem and as a result were priced at appropriate scarcity or shadow values. NNP was correctly valued given those shadow prices: F_X, $\frac{df}{db}$, and $U_{\dot{X}}/U_C$. In real-world economies there is generally no direct link between prices and pollution variables. Generally the pollution stock will be excessive because appropriate charges for using airsheds and watersheds are not in place. To move from our abstract ideal valuations to actual evaluations is very difficult. When inputs are improperly priced, the wrong levels of outputs are produced at the wrong prices. Un- or under-priced environmental capital services are generally mispriced inputs. In actual problems, then, GNP has to be adjusted to take account of implicitly properly priced outputs and then, the appropriate netting out of depreciation of the environmental capital must be done.

Concluding Remarks

We have presented a consistent logical framework for adjusting the national accounts to incorporate the use of natural resource capital, year by year. We drew on the fact that the current value Hamiltonian in an aggregate growth model is the NNP function in units of utility. We then indicated how to "purge" this function of utility units and obtain measures of "capital consumption" for all capital goods, both produced and those in nature such as oil pools, fish stocks, and airsheds. We dealt with each type of natural resource capital separately. This was convenient for communicating the central ideas. There is no conceptual difficulty in dealing with all types of capital goods simultaneously and observing that the rules for depreciating each type are unchanged from those rules we arrived at above. The trend in the correct measure of NNP per capita would indicate more accurately how much actual economic growth has been occurring. The correct measure reflects environmental degradation in a general sense, a sense which also is rooted in traditional capital theory.

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