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Pollution and National Accounting

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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 environmental capital (more pollution) is representable as an easy-to-interpret economic depreciation magnitude. We obtain a result which indicates when it is valid to net pollution abatement expenditures from GNP. We also obtain the general result: deduct rents on environmental capital reductions from GNP to get NNP.

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Introduction

The idea of defining net national product (GNP minus the "capital consumption allowance") net of natural resource stock depreciation has been proposed by Nordhous and Tobin [1972], Usher [1981], Ward [1982], El Serafy [1981], Stauffer [1985], Ward [1982], Eisner [1988], Bartelmus, Stahmer, van Tongren [1989], Repetto [1989] and others. A procedure grounded in capital theory is implicit in Weitzman [1976], and Solow [1986], who focus on exhaustible resource stocks as do the other contributors above except Nordhous and Tobin. In Hartwick [1989a] I develop the Weitzman-Solow approach in detail and indicate extensions. Here I report on deductions from GNP to allow for the degradation of environmental capital arising from increases in the stocks of pollutants residing in airsheds and watersheds. Needless to say the problem is harder to deal with than that with say exhaustible resources because of property rights failures associated with environmental capital. We return to this issue near the end.

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 environmental capital, net "investment" includes the economic depreciation (value of declines) in these environmental

*Kirk Hamilton suggested having human produced abatement operate on γ below rather than on b as I did earlier. The steps and rules remain unchanged in principle with this revision. My thanks to him for an interesting suggestion.

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 environmental capital stocks due to increased pollution over the accounting period, say one year.

We take up three variants of the approach - each turning on where pollution impinges in the economy and where abatement activities originate. First we consider no human abatement activity and negative pollution stock effects in the production function. Then we consider produced abatement activity and again negative pollution stock effects in the production function. Finally we introduce pollution effects in consumption activity or into the utility function. We add an "effect" at each stage. We observe (1) that there is a formal justiciation for netting pollution abatement costs from GNP (e.g., Peskin [1976]) in one variant and (2) that there is a netting out of rents on environmental capital in another variant. The netting out of exhaustible resource rents is introduced in Solow [1986] in his (and here, our) framework and is discussed in Hartwick [1989] and Hartwick and Lindsey [1989].

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).[1] In addition the production of this composite output

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

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 aggregate planning problem has a single control variable C and two state variables, namely K and X, as in maximize $\int_0^{\infty} e^{-\rho t} U(C)dt$ subject to $\dot{K} = F(K, L, X) - C$ and $\dot{X} = -bX + \gamma F(K, L, X)$ where ρ is the social discount rate and C is aggregate consumption. X(0), K(0) and L(0) are given exogenously. The current value Hamiltonian is

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

The canonical equations are

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

$$\dot{\phi} = \rho\phi - \frac{\partial H}{\partial K} \quad \text{or} \quad \dot{\phi} = \rho\phi - \phi F_K + \psi\gamma F_K$$

$$\dot{\psi} = \rho\psi - \frac{\partial H}{\partial X} \quad \text{or} \quad \dot{\psi} = \rho\psi - \phi F_X + \psi\gamma F_X + \psi b$$

$$\dot{K} = \frac{\partial H}{\partial \phi} \quad \text{or} \quad \dot{K} = F(K, L, X) - C$$

$$\dot{X} = \frac{\partial H}{\partial \psi} \quad \text{or} \quad \dot{X} = -bX + \gamma F(K, L, X)$$

To see that H(t) is the NNP function, we represent $U(C) = C \cdot U_C$, observe $U_C = \phi$, and divide through by U_C to get

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

or NNP inclusive of economic depreciation in environmental capital represented by $(\psi/U_C)\,\dot{X}$. Using the canonical equations further yields

$$\psi/U_C = \left[\frac{-\frac{\dot{U}_C}{U_C} + \rho - F_K}{\gamma F_K}\right] \equiv V.$$ Note that $V\dot{X}$ is depreciation in terms of the pollution stock rather than the stock of environmental capital. This is a convenient way to model environmental resources.

In the absence of pollution, V = 0 because the numerator of V is zero. The numerator is in units of <u>rate of return</u> 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 <u>the</u> 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. 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

$f(\gamma)$ as a debit from the produced composite output. A lower value of γ implies more rapid cleansing of stock X per unit time. The reduction of X is sped up for lower γ. Our current value Hamiltonian becomes

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

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 $f'\phi = F\psi$. Then $\frac{\psi}{U_C} = \frac{f'}{F} < 0$ because $f' < 0$ and economic depreciation is $\frac{\psi}{U_C}\dot{X} = \frac{f'\dot{X}}{F}$ where f' is the marginal cost of decreasing the flow of produced pollution by investment in abatement "capital", a function of γ. Note $\frac{-df}{Fd\gamma}$ is the extra composite commodity foregone, namely df which achieves extra abatement $-Fd\gamma$ 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 the γ technology. To achieve reduction $\dot{X}(< 0)$, the amount of composite commodity used up is, to a linear approximation, $-\frac{\Delta f}{\Delta X}\dot{X}$ $\left(\equiv \frac{-f'\dot{X}}{F}\right) > 0$. $\dot{X} > 0$ is equivalent to losing abatement resources, $\frac{\Delta f}{\Delta X}\dot{X}$, (<0). The economic depreciation taken out of GNP is $\frac{\Delta f}{\Delta X}\dot{X} < 0$ for $\dot{X} > 0$ or a lower stock of environmental capital, and this term now resembles those derived elsewhere for exhaustible 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 as an increment in pollution, $\dot{X}$, multiplied by the marginal cost of abating a unit of stock X. This is very different 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 $\frac{f'\dot{X}}{F} > 0$ 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

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

Relations $\frac{\partial H}{\partial C} = 0$ and $\frac{\partial H}{\partial b} = 0$ yield $\frac{\psi}{U_C} = \frac{-U_{\dot{X}}}{U_C} + \frac{f'}{F}$ 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 $\frac{f'}{F} < 0$ 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 $\frac{-f'}{F} + \frac{U_{\dot{X}}}{U_C} > 0$ and economic depreciation is $\frac{\psi(t)}{\phi(t)}\dot{X} \equiv -\left[\frac{U_{\dot{X}}}{U_C} - \frac{f'}{F}\right]\dot{X} < 0$ for $\dot{X} >$ 0, which should be added to GNP to obtain the lower correct NNP. Because X is a capital bad (as opposed to a capital good) our result is mirror symmetric to results for exhaustible resources. We have a sign change. Elsewhere economic depreciation was $[p\text{-}mc]\dot{\alpha}$ 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 $[p\text{-}mc]\dot{X}$ 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, $\frac{df}{d\gamma}$, 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. The trends in an adjusted NNP would provide a better indicator of how a nation's welfare is changing over time than say current NNP unadjusted for natural resource stock depreciation.

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