Appendix 19.2 Adjusting national income measurement to account for the environment

In this appendix we explore further the approach to national income measurement developed in Appendix 19.1, by applying it to models which capture other dimensions of the economy–environment interrelations that underlie an interest in environmental accounting. The caveats of Appendix 19.1 regarding the interpretation of the results as measures of sustainable income in the sense generally understood also apply here. We will, however, concentrate here on deriving the adjustments, rather than pursuing those issues in more general contexts.

Consider first a non-renewable resource-using model economy, which is that of Appendix 19.1 modified such that resource extraction is costly and there is exploration activity. The optimisation problem is

$$\text{Max}\int_0^\infty U\left(C_t\right)e^{-\rho t}dt \text{ subject to } \dot{S}_t = -R_t + N_t$$

$$\text{and } \dot{K}_t = Q\left(K_{t,}R_t\right) - C_t - G\left(R_{t,}S_t\right) - F\left(N_t S_t\right)$$

where N_t is new discoveries brought about by exploration activity with the cost function $F(N_t, S_t)$, such that costs rise with the level of exploration activity, $F_N = \partial F_t \partial N_t > 0$, and as the stock of resources is depleted, $F_S = \partial F_t / \partial S_t < 0$. The costs of extraction are given by $G(R_t, S_t)$, as in Appendix 15.3.

For this problem the current-value Hamiltonian is

$$H_t = U(C_t) + P_t(-R_t + N_t) + w_t(Q\{K_t, R_t\} - C_t$$
$$- G\{R_t, S_t\} - F\{N_t, S_t\})$$

with necessary conditions which include

$$\partial H_t/\partial C_t = U_C - w_t = 0 \qquad (19.47a)$$

$$\partial H_t/\partial R_t = -P_t + w_t Q_R - w_t G_R = 0 \qquad (19.47b)$$

$$\partial H_t/\partial N_t = P_t - w_t F_N = 0 \qquad (19.47c)$$

Note from equations 19.47b and 19.47c that

$$\mathrm{P_t/w_t = Q_R - G_R = F_N}$$

so that marginal discovery cost, F_N, is equal to marginal rent, $Q_R - G_R$.

The maximised Hamiltonian can be written as

$$H_t^* = U(C_t)\ w_t \dot{K}_t + P_t \dot{S}_t$$

and using $U = U_C C$ and $U_C = w_t$ we can write

$$\mathrm{EDP}_t = H_t^*/U_C = C_t + \dot{K}_t + (P_t/w_t)\dot{S}_t$$

which is

$$\mathrm{EDP}_t = C_t + I_t - (P_t/w_t)(R_t - N_t)$$

$$= \text{NDP}_t - (Q_R - G_R)(R_t - N_t)$$

$$= \text{NDP}_t - (Q_R - G_R)R_t + (Q_R - G_R)N_t$$

$$= \text{NDP}_t - (Q_R - G_R)R_t + F_N N_t$$

so that EDP_t for this economy is NDP_t less the depreciation of the non-renewable-resource stock, which is the total Hotelling rent; that is, marginal rent multiplied by extraction net of new discoveries.

Now consider the use of renewable resources in production, so that the current-value Hamiltonian is

$$H_t = U(C_t) + P_t(F\{S_t\} - R_t) +$$

$$w_t(Q\{K_t, R_t\} - C_t - G\{R_t, S_t\})$$

where R_t is resource use again and $F(S_t)$ is the intrinsic growth function. In Chapter 17 we used $G(S_t)$ for this function, but here we retain $G(\cdot)$ for the cost function so as to make the results now to be derived readily comparable with those for the non-renewable resource model just considered.

Note that harvest cost depends on the size of the harvest and the stock size. The necessary conditions here include

$$\partial H_t/\partial C_t = U_C - w_t = 0 \qquad (19.48a)$$

$$\partial H_t/\partial R = -P_t + w_t Q_R - w_t G_R = 0 \qquad (19.48b)$$

where equation 19.48b implies

$$\text{P}_\text{t} = \text{w}_\text{t}(\text{Q}_\text{R} - \text{G}_\text{R})$$

The maximised Hamiltonian can again be written

$$H_t^* = U(C_t) + w_t \dot{K}_t + P_t \dot{S}_t$$

and, proceeding as previously, we get

$$\text{EDP}_t = C_t + I_t + (P_t/w_t)\dot{S}_t$$

$$= \text{NDP}_t - (Q_R - G_R)(R_t - F\{S_t\}) \quad (19.48c)$$

which is the direct analogue to the result for a non-renewable resource. Here the marginal rent is multiplied by the harvest net of intrinsic growth. Note that if there is sustainable yield harvesting, $R_t = F(S_t)$ and no adjustment to NDP_t is required.

Suppose now that the renewable resource is not an input to the production of the consumption/capital good, but is an argument in the utility function. The production input case might be thought of as the way timber gets used, the utility function argument case as the way fish get used – whereas timber gets used to produce commodities for consumption, fish gets directly eaten. For this latter case,

$$H_t = U(C_t, R_t) + P_t(F\{S_t\} - R_t) +$$

$$w_t(Q\{K_t\} - C_t - G\{R_t, S_t\})$$

with necessary conditions which include

$$\partial H_t/\partial C = U_C - w_t = 0 \quad (19.49a)$$

$$\partial H_t/\partial R_t = U_R - P_t - w_t G_R = 0 \quad (19.49b)$$

which imply

$$U_R/U_C = (P_t/w_t) + G_R \qquad (19.49c)$$

for the price of caught fish available for consumption; that is, the consumption price of fish is marginal rent plus marginal cost. Using $U(C_t, R_t) = U_C C_t + U_R R_t$ and proceeding as before,

$$\text{EDP}_t = H_1^*/U_C = C_t + (U_R/U_C)R_t + \dot{K}_t + (P_t/w_t)\dot{S}_t$$

$$= (C_t + \{U_R/U_C\}R_t) + I_t + (P_t/w_t)(F\{S_t\} - R_t)$$

which by equation 19.49c and using C_t* for aggregate consumption is

$$\text{EDP}_t = C_1^* + I_t - (P_t/w_t)(R_t - F\{S_t\})$$

$$= \text{NDP}_t - (P_t/w_t)(R_t - F\{S_t\})$$

$$= \text{NDP}_t - (\{U_R/U_C\} - G_R)(R_t - F\{S_t\}) \qquad (19.49d)$$

This has the same structure as equation 19.48c in that EDP_t is NDP_t less depreciation, but note that P_t/w_t, used to value the change in stock size, is different in this case.

A third plausible specification for a model of an economy exploiting renewable resources has the harvest as an input to production and the stock size as an argument in the utility function. Thus, for example, harvested timber is used in production, while standing timber is a source of aesthetic pleasure and recreation. In such a case, the Hamiltonian is

$$H_t = U(C_t, S_t) + P_t(F\{S_t\} - R_t) +$$

$$w_t(Q\{K_t, R_t\} - C_t - G\{R_t, S_t\})$$

and the necessary conditions include

$$\partial H_t/\partial C_t = U_C - w_t = 0 \quad (19.50a)$$

$$\partial H_t/\partial R_t = -P_t + w_t Q_R - w_t G_R = 0 \quad (19.50b)$$

where equation 19.50b implies

$$P_t = w_t(Q_R - G_R) \quad (19.50c)$$

Then using $U(C_t, S_t) = U_C C_t + U_S S_t$

$$H_t^*/U_t = C_t + (U_S/U_C)S_t + \dot{K}_t + (P_t/w_t)\dot{S}_t$$

and

$$\text{EDP}_t = \text{NDP}_t + (U_S/U_C)S_t$$
$$- (Q_R - G_R)(R_t - F\{S_t\}) \quad (19.50d)$$

As compared with equation 19.48c there is a structural difference here. As well as subtracting depreciation from NPD_t, it is now necessary to add the value of the stock of the renewable resource, where the valuation uses U_S/U_C. Note further that in this case, we would generally assume that there was no market in the consumption of the amenity services provided by the stock, so that this ‘price’ could not be revealed in fully competitive markets, but would have to be ascertained by the sorts of methods discussed in Chapter 12.

The point being made here in looking at these three renewable resource models is that what we think we have to do to go from NDP to EDP, in terms of the nature of the adjustments and the valuations used with them, depends on the model that is used to analyse the problem. Since reasonable people may reasonably disagree about the specification of the model that captures the stylised facts of the way economic activity uses environmental services, it follows that there is no single correct answer to the question of how to get from NDP to EDP. Also, the answer may imply the need for non-market valuation, even if we are prepared to assume fully competitive markets where markets operate. The same point arises if we consider the matter of pollution and arising environmental degradation.

To illustrate this consider the model from Chapter 16, which has an index of environmental quality affecting both utility and production, where that index is a function of the current flow of residuals and the accumulated stock, where the production function recognises the materials balance principle, and where clean-up is undertaken. The optimisation problem is

$$\text{Max } \int_0^\infty U\left(C_{t,} E\{R_{t,} A_t\}\right) e^{-\rho t} \text{ subject to } \dot{S} = -R_t$$

$$\dot{K}_t = Q\left(K_{t,} R_{t,} E\{R_{t,} A_t\}\right) - C_t - G\left(R_{t,} S_t\right) - V_t$$

$$\dot{A} = M\left(R_t\right) - \alpha A_t - F\left(V_t\right)$$

Here $G(\cdot)$ is extraction cost, V_t is clean-up expenditure and $F(V_t)$ is the effect of that expenditure.

The current-value Hamiltonian is

$$\begin{aligned} H_t &= U\left(C_{t,} E\{R_{t,} A_t\right) + P_t\left(-R_t\right) \\ &\quad + w_t\left(Q\{K_{t,} R_{t,} E\left(R_{t,} A_t\right)\} - C_t - G_t\left(R_{t,} S_t\right) - V_t\right) \\ &\quad + \lambda_r\left(M\{R_t\} - \alpha_t A_t - F\{V_t\}\right) \end{aligned}$$

with necessary conditions including

$$\partial H_t / \partial C_t = U_C - w_t = 0 \qquad (19.51a)$$

$$\partial H_t/\partial R_t = U_E E_R - P_t + w_t Q_R + w_t Q_E E_R$$

$$- w_t G_R \lambda_t M_R = 0 \qquad (19.51b)$$

$$\partial H_t/\partial V_t = -w_t - \lambda_t F_V = 0 \qquad (19.51c)$$

From equation 19.51c

$$\lambda_t/w_t = -1/F_V \qquad (19.51d)$$

and using this and equation 19.51a in equation 19.51b gives

$$P_t/w_t = (U_E E_R/U_C) + Q_R + Q_E E_R - G_R - (1/F_V)M_R$$

$$= (Q_R - G_R) + (\{U_E/U_C\} + Q_E)E_R - (1/F_V)M_R \qquad (19.51e)$$

The maximised value of the Hamiltonian can be written

$$H_t^* = U(C_t, E\{R_t, A_t\}) + P_t \dot{S}_t + w_t \dot{K}_t ++ \lambda \dot{A}_t$$

and using $U(\cdot) = U_C C_t + U_E E_t$ and dividing by $U_C = w_t$

$$\text{EDP}_t = H_t^*/U_C$$

$$= C_t + (U_E/U_C)E_t + \dot{K}_t + (P_t/w_t)\text{F}_t + (\dot{S}_t/w_t)\ \dot{A}_t$$

or

$$\text{EDP}_t = \text{NDP}_t + (U_E/U_C)E_t - (P_t/w_t)R_t$$

$$+ (\lambda_t/w_t)(M\{R_t\} - \alpha A_t - F\{V_t\})$$

which on substituting for P_t/w_t from equation 19.51e and rearranging can be written as

$$\mathrm{EDP}_t = \mathrm{NDP}_t + (U_E/U_C)E_t - (Q_R - G_R)R_t$$
$$- (\{(U_E/U_C) + Q_E\}E_R - (1/F_V)M_R)R_t$$
$$- (1/F_V)(M\{R_t\} - \alpha A_t - F\{V_t\}) \quad (19.51f)$$

So, going from NDP to EDP now involves four adjustments. While the first two are easy to interpret (the second is just depreciation of the resource stock) an intuitive interpretation of the latter two is complicated. For our purposes there are two import-ant points. The first is that implementing these adjustments would require non-market valuation. The second is that if the environmental quality does not affect utility, $U_E = 0$ so that the first adjustment in equation 19.51f is not required and the third is modified. For any particular pollutant, whether $U_E = 0$ should be assumed or not is an empirical question, which would have to be decided by non-market valuation.

As another example of the dependency of the adjustment prescription on model specification, suppose that $M(R_t) = \beta R_t$ and E_t is a function only of A_t. Then the model might represent carbon dioxide emissions and the climate change problem, where gross emissions are a fixed proportion of the mass of fossil fuel, R, burned, and where it is only the concentration in the atmosphere that is relevant to climate change, which affects utility and production. In this case, clean-up can be thought of as tree planting. Then, with $E_R = 0$ equation 19.51e becomes

$$P_t/w_t = Q_R - G_R - (\beta/F_V)$$

and equation 19.51f becomes

$$\mathrm{EDP}_t = \mathrm{NDP}_t + (U_C/U_E)E_t - (Q_R - G_R)R_t$$
$$+ (\alpha A_t)/F_V + F(V_t)/F_V \quad (19.52)$$

which again illustrates the dependence of the necessary adjustments on model structure and assumptions.