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Theory and Applications

Green accounting using imperfect, current prices

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ABSTRACT. Especially in developing countries, natural resources and the environment are not optimally managed. Even so, it is possible for green accounts based on current prices to measure the realized contributions of the environment to net product. The prices for use in the green accounts, however, are not necessarily shadow prices as would be recommended by cost–benefit analysis: in practice, green or comprehensive NNP is an approximation of an index of welfare. The fact that a linearization of generalized national income is used implies that disaggregated, partial-equilibrium models of resources are useful.

1. Introduction

The goals of green accounting are to measure the value of the contribution of the environment to human welfare as a flow and the value of the degradation of the environment as a change in present value. The literature on the subject is ably summarized and extended by Aronsson and Löfgren (1998) and Asheim (2000). In their models, the objective is to maximize the integral of discounted social utility. For this objective, the optimal program can be supported by the equilibrium prices of an undistorted, competitive economy. Moreover, a generalization of net national product (NNP) is an index of the current level of social welfare (Weitzman, 2000).

A central environmental issue for developing countries is valuation when the policy being followed is inefficient, so that welfare is not being maximized. Indeed, the main reason for the gathering of national accounts, historically and currently, is that economies are perceived to function inefficiently. As Dasgupta and Mäler (2000) insist, green accounting must apply to the economy's realized path, as opposed to the optimal path, and hence the theory must be applicable to any feasible path. We concur that it

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would be unproductive for the assessment of national economic performance to estimate contributions or depletion as the levels which could be achieved if a resource were being exploited optimally. Rather, a resource's value is low if it is poorly managed, just as a corporation with great potential may have a low share value if the company is poorly managed. Similarly to corporate accounts, policy analysts use the green accounts to point out that a poorly managed resource provides a lower level of green national income, and likely of welfare, than is possible. With this information, one can propose how the realized level of national income can be increased.

Aronsson and Löfgren demonstrate that, if the economy is non-autonomous[1] or distorted, then the generalization of NNP should incorporate a missing term representing the integral of discounted future effects relating to the exogenous changes or distortion. The economic interpretation is that the agents in the economy are constrained from being able to optimize fully, and so the invisible hand cannot work perfectly; there is an economic variable which has a shadow value but is not subject to control. Since the missing term involves the entire future of the economy, it would appear that a measure of welfare involving only current values, comparable to the traditional NNP, cannot be constructed.

The present paper is more sanguine that the contribution, value, and depletion of an environmental resource, which may or may not be well managed, can be measured using values applicable to the current point in time. In practice, however, these values may not be the economy's optimal shadow values as given by a cost–benefit analysis. Green NNP requires, then, care in interpretation comparable to traditional NNP.

2. Drift

A non-autonomous economy has some source of exogenous 'drift' of important variables through time. Consider a simple economy which has a stock of non-renewable resource, R, and which is subject to pollution. At any time t, let consumption, C, the stock of pollution, S, and the flow of environmental amenities, A, be the arguments of the instantaneous utility function, $U(C,S,A|t)$. The utility function is conditioned on time t because tastes may change exogenously through time. Let consumption and gross investment, I, be produced by a production function involving capital, K, and the flow of the resource, $q = -\dot{R}$.[2] That is to say, let $C + \phi\,(I,t) = F(K,q,t)$, where $\phi\,(I,t)$ is the investment cost (in terms of the consumption good); $\partial\phi/\partial I > 0$; and the argument t captures exogenous changes through time. Let capital deteriorate at rate δ, so that $\dot{K} = I - \delta K$. To the utility flow let a discount factor, $\gamma(t)$, be applied at time t. Suppose that (contrary to present possibilities), all externalities are internalized by appropriate institutions from which prices corresponding to shadow prices emerge. Let the objective of the economy be to maximize the integral of discounted utility, $\int_t^\infty U(C,S,A|s)\,[\gamma(s)/\gamma(t)]ds$. This is the objective that would be pursued in an

[1] That is to say, if there are exogenous changes in technology, the environment, the discount rate, or the utility function through time.

[2] A dot over a variable denotes a rate of change: $\dot{R} = dR/dt$, etc.

economy-wide cost–benefit exercise. The integral has the properties of a Bergson–Samuelson social *welfare* functional. But also, as the discounted integral of the flow of a dividend which is the objective of the planner, it can be identified as social *wealth*.

The current-value Hamiltonian for the optimization problem is

$$H = U(C,S,A|t) - uq + v(I - \delta K) + w\dot{S}$$

u, v, and w being the shadow values of a unit of resource, of capital and of pollution. A *linearization* of this Hamiltonian is given by

$$H_0 = C\frac{\partial U}{\partial C} + S\frac{\partial U}{\partial S} + A\frac{\partial U}{\partial A} - uq + v(I - \delta K) + w\dot{S}$$

Utility can be scaled so that the market price of the consumption good is given by $\partial U/\partial C = p$. In this case, the market price of investment goods is v. This linearized Hamiltonian is an extension of the traditional net national *expenditure* (NNE) at market prices, $pC + v\,(I - \delta K)$: it incorporates four new terms to account for the value of the environment. Therefore, it is called the *green* NNE.

The linearization abstracts from aggregate consumers' surplus, $V = U - C\partial U/\partial C - S\partial U/\partial S - A\partial U/\partial A$. Because a cost–benefit analysis evaluates (any increase in) consumers' surplus as a benefit, it differs from national accounting.[3]

The theory of dynamic programming allows us to express the current discounted utility as a function dependent on time and on the stocks of resources and pollution

$$\int_t^{\infty} U(C,S,A|s)\,[\gamma(s)/\gamma(t)]ds = W(R_t,K_t,S_t,t)$$

By the first fundamental theorem of calculus

$$\dot{W} = (-\dot{\gamma}/\gamma)W - U(C,S,A|t)$$

Let $W(R,K,S,t)$ be a differentiable function of all of its arguments. Then by differentiation of the function W and the property that the partial derivatives of the objective function are equal to the shadow values

$$\dot{W} = \frac{\partial W}{\partial R}\dot{R} + \frac{\partial W}{\partial K}\dot{K} + \frac{\partial W}{\partial S}\dot{S} + \frac{\partial W}{\partial t}$$
$$= -uq + v(I - \delta K) + w\dot{S} + \partial W/\partial t$$

We can rearrange these equations to find that

$$(-\dot{\gamma}/\gamma)W = U(C,S,A,t) - uq + v(I - \delta K) + w\dot{S} + \partial W/\partial t = H + \partial W/\partial t$$

Interest on social wealth, $(-\dot{\gamma}/\gamma)W$—generalized national *income*—is equal to the Hamiltonian from the optimization problem plus an additional

[3] The expression for consumers' surplus is a correct aggregate measure, and is not subject to income effects which cause the consumers' surplus measured using a Marshallian demand curve to diverge from the correct value from a Hicksian demand curve.

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term, $\partial W/\partial t$. This additional term captures any exogenous changes in social preferences U, in social time preferences γ, in technology and in the environment. The last might be such changes as climate change not induced by humans.

The welfare interpretation of green, or extended, NNP in an undistorted economy relies on the fact that the linearization of the Hamiltonian, H_0, which is generalized national expenditure, is an approximation *at the margin* to generalized national income, $(-\dot{\gamma}/\gamma)W$. For small changes, if green NNE increases then wealth, or social welfare, increases. Varian (1992: 408) presents the analysis for a static economy; since it is only utility which is affected by the linearization of the Hamiltonian, the extension to a dynamic economy is immediate. An increase in discounted utility increases the value of green NNP, and an increase in green NNP in all likelihood increases discounted utility. Increasing net investment means increasing discounted utility, since net investment is defined to be $\dot{W}$, the appreciation or depreciation of wealth.

Only if the drift is significant (only if $\partial W/\partial t$ is large) is there a significant error in using the Linearized Hamiltonian, H_0, as an index of welfare in an optimal economy. If all endogenous economic forces are accounted for, as is usually assumed in models such as this, then drift is apt to be slow and its value low. Even if it is significant, the drift $\partial W/\partial t$ $(= \dot{t}\partial W/\partial t$ since $\dot{t} = 1)$ is formally similar to the other net investments, $\dot{R}\partial W/\partial R$, $\dot{S}\partial W/\partial S$ and $\dot{K}\partial W/\partial K$. It can be considered to be the current shadow value of time and incorporated in the same way as the other extensions. Though W and $\partial W/\partial t$ depend on what happens throughout the future, any extension to NNP involves a current shadow price. Moreover, the optimal path corresponds to a perfectly decentralized path (cf. Asheim, 2000), under the provision that appropriate institutions are in place to recognize the value of pollution (w) and resource use (u).

Therefore, current shadow prices can be used in an indicator of welfare in an optimal economy, be it autonomous or non-autonomous. Linearization of the Hamiltonian provides a theoretical justification for

1. the use of market prices to value marketed goods and shadow prices to value non-marketed goods, as well as
2. summing across individuals' use of goods and across goods to obtain the indicator of welfare.

Because the economy decentralizes market prices to individual decision makers, the prices observed in individual markets can be used, and results aggregated to find a value for the whole economy.

3. Distortion

As in the analysis of optimal use, let the value function for a distorted (non-optimal) economy be the integral of discounted utility.[4] Since the

[4] Dasgupta and Mäler (2000) present a parallel development for a distorted economy. They study governments engaged in policy reform and utilize 'local accounting prices' which are the shadow prices for the economy to derive several theoretical results. Our purpose here is, in part, to consider the implications of extending NNP at market prices.

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planner's objective is not necessarily being maximized, our discussion relies on assuming the extension of 'sensitivity results' for a similar problem discussed by Seierstad and Sydsaeter (1987: 215–216).[5] In particular, we assume that the value of the planner's objective can be expressed as a function of the various stocks and of time, and furthermore that it is a monotone, differentiable function of each stock. Along the economy's actual path, then

$$\tilde{W}(R_t, K_t, S_t, t) = \int_t^{\infty} U(C, S, A|s)\,[\gamma(s)/\gamma(t)]ds$$

The sensitivity results allow for a treatment of a distorted economy which is parallel to our treatment of an undistorted economy. In particular, national income can be approximated by a linearization which weights all variables at their shadow values in the distorted economy

$$\left(\frac{-\dot{\gamma}}{\gamma}\right)\tilde{W} \approx C\frac{\partial U}{\partial C} + S\frac{\partial U}{\partial S} + A\frac{\partial U}{\partial A} - \frac{\partial \tilde{W}}{\partial R}q + \frac{\partial \tilde{W}}{\partial K}(I - \partial K) + \frac{\partial \tilde{W}}{\partial S}\dot{S} + \frac{\partial \tilde{W}}{\partial t}$$

The expression for national income corresponds with the linearized Hamiltonian, but the welfare interpretation does not depend on the properties of the Hamiltonian in an optimal control.

In textbook analyses, utility can be scaled such that the marginal utility of a consumption good is equal to the market price. If prices are distorted, however, market prices are unlikely to be the opportunity costs prescribed by a cost–benefit analysis. For example, if there is an externality, the market price is not the (aggregate) marginal utility of the good, although it is the consumer's own marginal utility. If a good is rationed, price is not marginal utility. By the same token, if capital is traded, the shadow value (opportunity cost) of capital, $\partial\tilde{W}/\partial K$, is its border price (Drèze and Stern, 1987; Squire, 1989). In national expenditure, the value of net investment is taken to be the market price. Up to such deviations from correct shadow prices, which are well-understood because they arise in the traditional accounts, what is traded in markets is correctly accounted.[6]

But depletion is traditionally not considered in the national accounts. Nor is the current disutility from pollution; nor the current marginal utility from environmental amenities; nor the current value of the change in pollution. The aim of *green* accounting is to incorporate into NNP estimates of the values of the environmental variables, $q\partial\tilde{W}/\partial R$, $S\partial U/\partial S$, $A\partial U/\partial A$, and $\dot{S}\partial\tilde{W}/\partial S$.

If the resource is mediated on markets then, analogously to capital, the border price is the correct, observable measure of $\partial\tilde{W}/\partial R$ for a cost–benefit analysis. By analogy with the treatment of capital, the market price is a practical substitute in the green accounts. The values of additions to

[5] The sensitivity result discussed applies to a problem with a fixed end point. Seierstad has provided conditions which are sufficient for the extension we are contemplating; see Aronsson, Johansson, and Löfgren (1997: 72).

[6] Indeed, if there is a deviation, using border rather than market prices could do damage to the important theoretical equality between national income and national expenditure, which provides verification of the values obtained.

pollution, $\partial\tilde{W}/\partial S$, of the marginal disutility of the stock of pollution $\partial U/\partial S$ and of the marginal utility of environmental amenities, $\partial U/\partial A$, have to be imputed.

Imputing the shadow values $\partial U/\partial S$ and $\partial U/\partial A$ is difficult and controversial. But at least these are current values. Conceptually, valuing additions to pollution is more difficult because the value of additions to the stock involves the future of the economy. Seierstad and Sydsaeter's sensitivity results include an adjoint condition similar to that obtained in an optimization model. Integrating that condition yields that

$$\frac{\partial W}{\partial S} = \int_t^{\infty} \frac{\partial U}{\partial S} e^{-r(s-t)}\, ds$$

A current marginal increase of pollution will affect all future utility at the margin, and the value of that marginal addition is the total discounted marginal utility.

But the current price of a durable market good, such as a bicycle, also involves discounting the future. If environmental regulation is optimal, then the current marginal cost of compliance with environmental regulation is equal to $\partial W/\partial S$. Again from the point of view of cost–benefit analysis, compliance cost may be an imperfect measure because existing regulation may not correctly reflect social preferences.[7] If existing regulation is too lax, and is expected to become tighter through time, then the increasing marginal compliance cost will contribute to measured 'green growth' through an increase in green NNP. But if it is too stringent and expected to be loosened, the resulting decline in marginal compliance cost over time will be incorrectly seen as reducing green growth. As with marketed goods, one would enter the product of the estimated values (accounting prices) and quantities in NNP.

As with marketed goods, the welfare interpretation is only as valid as the estimates of the shadow values. In interpreting green NNP, one can take three positions.

1 Market prices can simply be assumed to be shadow prices.
2 The practice of the national accounts is to use market prices where possible and to be careful of imputations, and adherence to this practice is necessary to obtain valid statistics.[8]
3 In cost–benefit analysis, it is commonly held that what is important is to measure the right things, even if crudely, rather than to try to make refined estimates which may not add value for a decision maker. In this

[7] There is a sense in which it does: existing regulations reflect a balance among political forces at the margin, and hence the shadow value in the 'political market' (Becker, 1983; Horan *et al.*, 2000). Elsewhere in the national accounts, it is necessary to accept governmental expenditures and the results of regulations as being in the national interest.

[8] Early literature, such as some of the papers in the influential volume edited by Ahmad, El Serafy, and Lutz (1989), make a similar observation, but to our reading the reason is that the authors find merit in continuity with established methods. There may well be such merit. The current paper stresses the links of current practice with theory, in a context of seeking practicality.

sense, green accounting takes a major step by incorporating environmental values which have traditionally been neglected.

The suggestion that green accounts can be made up using current, imperfect price is based on an amalgam of these three ideas, an amalgam in which the relative weights may depend on the tastes of the analyst. In this amalgam, there is a symmetric treatment of like concepts from the model of the distorted economy. Flows which directly affect utility, such as consumption goods and flows of environmental amenities, are evaluated at market prices if available and otherwise by imputing shadow prices. Capital and capital-like goods, which affect utility through time, are evaluated at market prices if available, and through market expenditures if necessary.

4. Conclusion

In a perfectly competitive economy, an indicator of welfare can be constructed from current shadow prices. Properties of the linearization of the utility function justify the use of market prices in national accounting. When the linearization is carried over to the green accounts, the same value-added approach can be used for evaluating individual resources. This perception of the role of market prices corresponds exactly with their role in decentralizing decisions in a market economy. Thus, evaluations in partial equilibrium can be used as proxies for the general-equilibrium conditions on which theory rests, as in the traditional accounts.

An economy need not be following the optimal program, and hence need not be realizing its potential, in order for there to be useful green accounts based on current prices. In this case, the national accounts do not follow cost–benefit practice. In particular, consumers' surplus is neglected and market prices rather than border prices or other measures of opportunity cost are used. Even so, the formulae for the green accounts of an imperfect economy are formally the same as for a hypothetical optimal economy and are suggested by the analysis of the optimal economy. In this case, too, research based on partial-equilibrium models of individual enterprises is a valid guide to green-accounting prices. Green NNP is an imperfect indicator of welfare but, like traditional NNP, can be a useful statistic if its properties are appreciated.

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