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Natural resource accounting in theory and practice: A critical assessment*

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In this paper an extensive review of the theoretical and applied literature on natural resource accounting (NRA) is provided. The review begins by explaining the economic theory that underpins NRA, contrasting welfare and sustainability as policy goals, and presenting various distinct conceptions of national income. The state of play regarding official revisions to the system of national accounts (SNA) with respect to natural resources and the environment is presented and controversial areas are highlighted. Finally, the economic literature on proposed revisions, and applied studies that have proceeded using these methods, is summarised and critiqued. We argue that much of the literature proceeds with weak conceptual foundations, and that typical case studies produce results that are ambiguous in interpretation. Moreover, we highlight fundamental tensions between economic theory and national accounting methodology, and conclude that one outcome of this has been the insufficient attention paid by economists to the revisions to the SNA; instead devoting time and effort to 'freelance' NRA case studies utilising sometimes ad hoc methods from the economic literature.

1. Introduction

> There is a dangerous asymmetry in the way we measure … the value of natural resources … A country could exhaust its mineral resources, cut down its forests, erode its soils, pollute its aquifers, and hunt its wildlife to extinction, but measured income would rise steadily as these assets disappeared.
>
> (Repetto 1988, p. 2)

Economic activity inevitably entails interaction with the environment, either as resource use, as a sink for waste assimilation or as a source of amenity value. Traditional measures of economic activity such as Gross Domestic

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Product (GDP) and Net Domestic Product (NDP)[1], generated via the existing System of National Accounts (SNA), are recognised as being inadequate in terms of accurately measuring the contribution of, and impact on, the environment. Specifically, costs of environmental degradation and natural resource depletion, and non-market amenity values are not included.[2] Furthermore, defensive expenditures designed to offset pollution are counted as additions to GDP/NDP.

Thus, the present measures of economic performance that are given primary importance in public policy formation and debate can provide misleading information on which to base decision-making. Variables that contribute to economic well-being are excluded from national income calculations.[3] National income in its current guise, and in the current SNA, provides a poor reflection of both current and future standards of living. Hence environmental adjustments to the SNA and, more broadly, the introduction of Natural Resource Accounting (NRA) are advocated on the basis of removing the current biases.

Reviewing the main proposals for adjusting the accounts to rectify these biases is a key purpose of this paper. However, there are more analytical questions of interest than simply how the accounts should be modified. Why they should be modified also deserves attention. There are two questions here which are relatively under-researched: (i) what are we trying to measure, and (ii) what effect will adjusting our measures have? In answering the first question we are attempting to frame existing and proposed accounting processes in terms of clear measurement objectives. With the second question, we are examining how improved accounting practices are thought to lead to improved choices and better economic and environmental outcomes. In this paper we focus on the first question as opposed to the second because this has been the focus of the bulk of the existing literature. However, we note that the role of biased accounts in 'misguiding' policy, and the possibility for policy improvements resulting from changing the accounting system in particular directions is an under-researched topic. Deficiencies and disagreements in the NRA literature may, in part, be attributed to inadequate attention to the underlying policy questions that should have been posed in the first place.

One key feature of the NRA literature stressed in this review is its paradigmatic diversity. The literature is contributed to by economic theorists,

[1] The literature often refers to net and gross national product (NNP/GNP). We treat these as interchangeable with domestic product measures.

[2] We use the term environment broadly, encompassing both natural and environmental resources.

[3] For an early discussion of the discrepancies between GDP and a welfare index see Denison (1972).

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applied economists, ecological economists and national accountants. As a result, concepts, assumptions and terminology vary throughout the literature yielding tensions and inconsistencies. Ideally, the theory should provide a supporting conceptual framework for the practical recommendations regarding adjustments, which should, in turn, inform applied researchers. However, the various areas of work are not well-integrated at all. In some cases, linkages between them barely exist and in others there are significant tensions or conflicts. Evidence of cross-purpose confusion arises in the terminology used. Under the banner of NRA, references are made to 'resource accounting', 'environmental accounting' and 'Green GDP'. Sometimes they are interchangeable and other times they are separate and distinct processes or measures.[4]

The structure of this paper is as follows: we proceed from an examination of the theoretical underpinnings (Sections 2 and 3) to applications (Sections 4 and 5), concluding with an overall assessment in Section 6. In particular, Section 2 examines the key conceptual aspects and policy objectives of NRA, which are bound up (we contend) with arguments about how to define and measure well-being and sustainability. Section 3 presents a detailed discussion of income and growth, arguing that there is not one all-encompassing definition of income suitable for all purposes. In fact, part of the difficulty in the area involves how best to reconcile *ex post* income measures with *ex ante* income concepts. Section 4 then covers changes in official national accounting with regard to resources and the environment. Section 5 presents an overview of the economic literature, both conceptual and applied, presenting key case studies and critically examining methods and results. In Section 6 we provide conclusions.

2. What are we trying to measure and why?

> Do changes in national income and product over time or differences among nations really measure appropriately changes and differences in 'well-being' or, perhaps more to the point, 'economic well-being'? Do our measures show correctly the distribution of income and output within the population, their cyclical fluctuations, and their allocation to current consumption and accumulation of capital for the future? … Do our measures really fit the theoretical constructs they are presumed to serve?
>
> (Eisner 1988, p. 1612)

[4] Resource accounting sometimes refers to a limited approach using satellite accounts where natural resources are measured, sometimes in purely physical terms, while the main monetary aggregates (particularly GDP) remain unmodified. Environmental accounting can refer to adjustments reflecting pollution or changes in environmental amenities, while 'Green GDP' explicitly refers to adjustment of the major economic indicator.

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2.1 Exposing the System of National Account's shortcomings raises further questions

Conventionally measured GDP is constructed as a measure of the output of the market sector, yet in its interpretation as a nation's income, it is often presented as a measure of standards of living, and thus as a proxy for social welfare. However, conventionally measured GDP has serious deficiencies as a measure of genuine standards of living, especially with regard to the environmental impact of economic activity. Resource stocks whose use contributes to current income flows can be depleted without any corresponding adjustment in the accounts for this depletion, thus treating reductions in wealth as increases in income. Environmental assets *in situ* may be degraded due to economic activity, resulting in a reduction in social welfare, also without any corresponding adjustment being made in the accounts.

Yet simply identifying 'obvious' gaps in the SNA is only one analytical step. Other analytical questions remain, which we will use to frame the subsequent discussion in this paper. In particular, we will focus on two main questions.[5]

In the first question we ask what are we aiming to achieve in adjusting our measures of income and wealth? Put another way, what role is national income meant to perform? What would we like it to be a measure of? What signals might it provide to policymakers? Possible roles include (see for example Denison 1972; Eisner 1988; Rymes 1993):

1. As comparisons of standards of living over time
2. As comparisons of standards of living across countries
3. As an indicator of sustainable consumption
4. As a benefit-cost decision rule by which any action that increases the index has overall benefits exceeding the costs and thus should be undertaken.

The second question follows from the first. If we perform what we think are the appropriate adjustments to correct the shortcomings outlined, what sort of measure do we produce? Will it perform these idealised role(s)?

The next sections are aimed at discussing the first question. From there, we evaluate actual NRA proposals with a view to the second question.

[5] As indicated, other questions are neglected, in particular those related to the public policy/political economy aspects of NRA, resource management and sustainable development. In other words, how, and by what process, does better measurement lead to better decisions and outcomes? We confine our attention to a difficult enough question, which is 'better measurement of *what*?'

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2.2 Two dimensions of interest: welfare and sustainability

If the national accounts are flawed, why are they flawed? With respect to what dimension of economic or social concern? Two conceptual standards are regularly suggested, if often less than rigorously. They are, respectively, welfare and sustainability. That is, current measures of national income (e.g., GDP) are inadequate as indicators of social welfare, and moreover provide misleading information about whether an economy is using its resources sustainably. However, welfare and sustainability are distinct concepts; they may be related, but they are not the same thing. Will an adjusted index that contains information about trends in economic and social welfare also provide useful information about sustainable consumption and resource use?

Both welfare and sustainability are complex and multidimensional concepts. Welfare can involve material questions of income and consumption, as well as more complex societal questions of distribution and of well-being that results from personal contentment, relative social status and social tranquillity. Sustainability covers an amalgam of economic, environmental and social objectives. Thus, even looked at in isolation, it is not self-evident what these terms mean.

In the technical economics literature, welfare and sustainability are defined and explored through formal modelling.[6] Welfare is conceptually represented by a utility function that incorporates all relevant arguments that contribute to well-being. For example, environmental amenities, the distribution of income, or even unpleasantness due to the intensity of the morning traffic, may enter an individual's utility function.[7] This not only enables welfare to be formally analysed, but may also allow us to look at sustainability at a conceptual level, by defining sustainability in relation to intertemporal welfare. A standard approach (Pezzey 1989) is to define a sustainable path as one over which social welfare (instantaneous utility) is non-declining.

Immediately the distinction between welfare and sustainability as policy objectives becomes more visible. Economists typically use an optimising framework, in which some intertemporal version of the social welfare function is maximised subject to technological constraints and time discounting. Discounting immediately introduces the possibility that a path that satisfies a present value utility maximising criterion may fail a sustainability criterion. Welfare and sustainability may easily be conflicting

[6] See for example Pezzey (1989); Toman *et al.* (1995); and Dasgupta (1995).

[7] In intertemporal modelling, economists typically avoid aggregation issues by using a representative agent allowing an explicit focus on intergenerational issues, while avoiding the complexities of intragenerational distribution issues.

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criteria, with different ethical presumptions and implications, leading to different 'preferred' consumption paths over time. Furthermore, sustainability may be regarded as an objective in itself, or it may be brought in as a constraint against which some other objective is pursued.[8]

What are the practical implications of these conceptual distinctions? A simple way of contrasting the impact of alternative accounting practices on welfare-relevant and sustainability-relevant concepts of income is to imagine the following cases. If some form of pollution exists that is within the long-term absorptive capacity of the environment, but causes disamenities now, then it has consequences for current welfare but not for sustainability. If, on the other hand, damage is being done to a micro-organism that has implications for an important ecosystem, but has no impact on our way of life now, then that has consequences for sustainability but not for current welfare. Assuming the impacts of these could be appropriately measured, the interpretation of an adjusted NDP will self-evidently depend on the nature of the problem being adjusted for. Another example arises when considering the capital consumption allowance for resource use that is a standard NRA prescription (see Section 4). While a welfare emphasis may stress efficient resource use, an explicit focus on sustainability might require us to account for whether or not reductions in natural capital are being made up for by increases in other forms of capital by the reinvestment of resource rents. That is, in one context, the important consideration is the (optimal) rate of exploitation; in the other context, what matters is adherence to a reinvestment rule.

Thus, while welfare and sustainability must be related concepts, they are certainly not identical. Moreover, sustainability constraints can be applied at different levels of aggregation (global, national, regional and resource-specific), using different criteria (physical and monetary), and with different comparisons between actual and 'sustainable' outcomes. Toman *et al.* (1995) and Hanley (2000) present useful discussions of the tension between welfare and sustainability issues, as well as alternative ways to think about sustainability.

3. Understanding income and growth

> If national accountants could provide acceptable measures of the economic depletion of exhaustible natural resources and the economic degradation of our natural world, these, added to those for economic depreciation and deducted from Gross

[8] Pezzey's (1989) concept of 'opsustimal' growth, for example.

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> Product, would yield measures of Net Product which might show whether or not we have been experiencing sustainable consumption.
>
> (Rymes 1993, p. 199)

Any discussion of the appropriateness of SNA procedures and NRA must be based on a coherent and well-defined conception of income and growth. In this section, we discuss the meaning(s) of (national) income, and the related, but distinct concept of economic growth, emphasising the connections with welfare and sustainability concepts. This will help provide an interpretation of a 'greened' GDP generated by NRA, and place in context the role such a measure might play in the public policy process.

3.1 Definitions of income

There are (at least) two other standard definitions of income in the economics literature. One is an accounting based measure now known as the Schanz-Haig-Simons (SHS) definition of income. Schanz-Haig-Simons income, or Y_{SHS}, is defined as the sum of today's consumption plus the change in the market value of capital. This is the framework around which national accounts are built. The gross version (GDP) adds production of new capital to consumption, while the net version (NDP) then deducts depreciation, so only net capital accumulation is counted in income. This distinction is important when considering the depreciation of natural capital in the next section.

The second definition of income is particularly associated with the work of Hicks (1946) and is named Hicksian income or Y_{Hicks}. It derives from a thought experiment concerning the effect of current consumption on future consumption possibilities. Hicksian income is often thought of as being analogous to a return to wealth, in that it equals (in certain circumstances) that level of consumption that leaves overall wealth unchanged. Two important points should be noted here. First, the idea of Hicksian income as the amount that can be consumed while leaving wealth constant is only an approximation to Hicks's underlying idea of that amount that can be consumed without reducing future consumption prospects (we will talk more about the connection between constant wealth and constant consumption in the following text). Second, Hicksian income in this formulation is consumption-only, while SHS income is explicitly consumption plus capital accumulation[9] (the theoretical interpretation of a measure in which capital goods are added to consumption is discussed in Section 3.2).

[9] We could account for population growth by discussing per capita income and wealth, etc.

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In formal notation, denote Schanz-Haig-Simons income as:

$$Y_{SHS}(t) = c(t) + \dot{k}(t) \tag{1}$$

where c represents consumption and k is capital. Hicksian income, in contrast, is denoted:

$$Y_{Hicks}(t) = \max c(t) \text{ subject to } \dot{c}(t) \geq 0 \text{ for all } t \tag{2}$$

Although the SHS measure of income is the basis of national income measures such as GDP, Hicksian income is of interest as it provides a criterion of what we would like measured income to tell us. Bradford (1990) distinguishes between the two concepts of income as being a backward-looking measure (SHS income – how much value have we added?) and a forward-looking measure (Hicksian income – how much can we consume?). This accords with the distinction Hicks draws between *ex ante* and *ex post* income.[10] This raises an important question regarding the objectives of the national accounts, namely, when are we able to derive forward-looking information based on backward-looking data, such as those included in the national accounts? This question seems to be essential to any linking of NRA with sustainability (or some intertemporal welfare measure), as any such analysis requires us to link current activities to future impacts. A formal approach to this question is considered in the next sub-section.

As it is, with regard to the two measures of income, many economists regard the Hicksian and SHS concepts of income as almost interchangeable, despite the clear distinction Bradford draws. In theory, and under restrictive assumptions, Hicksian income is equivalent to SHS income, if the change in net wealth is zero. That is,

$$\tilde{Y}_{Hicks}(t) = \max c(t) \text{ subject to } \dot{k}(t) \geq 0 \text{ for all } t \tag{3}$$

This is an approximation to the ideal measure (2), in which maintenance of a constant capital stock is used as a proxy for constant (potential) consumption in future. According to this view, if net wealth accumulation is positive then future consumption possibilities are being enhanced. If net wealth accumulation is negative, net wealth is decreasing and future consumption prospects are being eroded (Rymes 1993; Aronsson *et al.* 1997). This principle of

[10] Hicks' discussion of income is very detailed and he provides a number of context-specific definitions. He, in fact, discusses both measures of income mentioned in the text, referring to the 'sustainable consumption' definition as *ex ante* income, and the 'consumption plus change in capital' as *ex post* income. This has led various authors to use different concepts of income and to label them all 'Hicksian'. Eisner (1990), Scott (1990) and Bradford (1990) debate the proper interpretation of what is known as Hicksian income. Nordhaus (1995, 2000) uses different terminology again between consumption-plus-change-in-capital income, capital-constant income, and sustainable-consumption income (he labels the latter 'Fisherian').

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maintaining a capital stock as a proxy for maintaining consumption possibilities motivates many applications of NRA examined in Section 5.

However, to view SHS income as embodying information on sustainability can result in dangerous oversimplifications. Several examples are given in the present article of why the relationship between income and wealth is more complex than the above view allows, although readers may well be able to think of others. The first example concerns the long-term interest rate. Put simply, constant/increasing/decreasing wealth is only a sufficient condition for constant/increasing/decreasing consumption prospects respectively, with a constant interest rate. If the interest rate declines over time, the return to a given stock of wealth will decline as well. It has been established in the literature that if exhaustible resources are economically 'important', then their gradual depletion will be reflected in declining interest rates (Asheim 1996, 1997), requiring reinvestment of some of the return to wealth in order to maintain consumption prospects.

Another example can be outlined as a question and answer. The question is, how is forward-looking information being embodied in the national accounts? The answer is, through prices. The valuation of net wealth must reflect a correct capitalised value of the capital stock's ability to generate future consumption and welfare. It is an act of great faith to claim that our present capital stock can be reliably valued in terms of the economy's true future consumption potential.[11]

One more example concerns the substitutability assumptions underpinning the capital-theoretic view of sustainability. Is it possible to substitute indefinitely for diminishing natural capital with increased or improved manufactured capital?[12] Note that this criticism differs from that in the previous example in which substitutability was assumed, but the appropriate pricing of individual items in terms of relative productivity was questioned.

These examples serve to show that there are theoretical issues that confound the link between income and wealth on which much of the NRA literature relies (i.e., the capital-theoretic view of sustainability). There are practical/policy issues concerning the economy finding the 'right' prices (including interest rates) to be on a sustainable path; and there are measurement issues regarding applying appropriate prices/valuations for welfare and/or sustainability purposes when calculating adjusted national income.

But the question that remains of interest as a benchmark is: if we were confident that our price system was efficient and that capital was sufficiently

[11] Another break in the nexus between SHS income and 'sustainable consumption' is provided by technological change. See Section 5.5 *Aggregate sustainable studies*.

[12] For a sceptical view see Stern (1997).

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substitutable, what conclusions could then be drawn about the future from an idealised measure of national income? This is discussed next.

3.2 The Hamiltonian approach: A conceptual reconciliation?

This section covers the most theoretically precise connection in the literature between today's income and social wealth. We start off by discussing the fundamental result, then move to a discussion of its implications for natural resource accounting, both in terms of welfare- and sustainability-relevant measures.

The general result

Our motivation here is as follows: if the Hicksian and SHS definitions are not identical, then we are entitled to ask questions about the purposes of national accounting exercises since there would appear to be no forward-looking information contained in the GDP. In particular:

1. Why include investment in income when the fundamental economic goal is consumption?
2. What can current economic data tell us about the future prospects of the economy?

Weitzman (1976) reconciled the welfare significance of a measure of current income that contains a combination of current consumption that contributes to current welfare, and investment that only contributes to future welfare. His contribution has inspired a considerable body of work, especially with regard to theoretical inquiries into NRA.[13] Weitzman (1998) explains his earlier contribution in terms of reconciling what he calls 'sustainable–equivalent consumption' with 'comprehensive NNP' (a fully adjusted national income measure). The result from this work is that real NNP at any date along an optimal consumption path reflects the economy's long run consumption possibilities. That is, NNP indicates the level of consumption, that if maintained at a constant level forever from today, would generate a present value of welfare equal to that of the competitive trajectory from today to the infinite future.

This is often referred to as the Hamiltonian approach as it is represented using the dynamic optimisation framework employed in optimal control theory. Subsequent work by authors such as Hartwick (1990) and Maler (1991) generalised the linear-utility framework employed by Weitzman; the connection with the Hamiltonian can be seen as follows. Let the Hamiltonian

[13] For a comprehensive examination of this approach, see Aronsson *et al*. (1997).

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for a simple economy (in which U is social welfare, c is consumption, k is capital and λ is the shadow price of capital) be given by:

$$H = U(c) + \lambda.\dot{k} \tag{4}$$

It is a standard result that $\lambda = U_C$ (that is, the shadow value of capital is just equal to the marginal utility from instantaneous consumption) along the optimal path. Dividing through by U_C and linearising around the marginal utility of consumption such that $U(c) \approx U_C.\ c$, then what Hartwick calls the 'dollar value' net product function is:

$$Y_{WHM} = \frac{H}{U_C} = NNP = c + \dot{k} \tag{5}$$

This *NNP* index (referred to as WHM income, for Weitzman–Hartwick–Maler) can, by Weitzman's analysis, be regarded as a return to wealth, where wealth is the discounted sum of future consumption (in the non-linear version, *NNP* is a linear approximation to a return on discounted future utility).

The Hamiltonian and natural resource accounting

Weitzman mentions but does not investigate depreciation of types of capital such as exhaustible natural resources. Not until Solow (1986) was there an explicit application of Weitzman's result to issues of resource depletion. This was followed by the generalised analyses of Hartwick (1990) and Maler (1991), summarised above, which have in turn generated extensive literature applying this formal approach to environmental accounting issues.

The two main and inter-linked contributions of the Hamiltonian approach to income in the NRA literature are to provide interpretations of an aggregate index number in terms of welfare economics (and sometimes sustainability; see the following discussion); and to derive the accounting adjustments necessary to admit such an interpretation. In other words, what adjustments are needed to GDP for resource depletion, pollution, and so on, to enable us to produce an income measure that has a meaningful economic interpretation? Here we focus on the interpretations that arise from this model; Section 5 discusses the accounting adjustments that arise from these models and from other areas of the literature.

The key interpretation of the Hamiltonian model of national income is that such income can be expressed as a return to wealth, wealth being discounted future consumption/utility. Another way of putting this is that today's NDP is proportional to discounted social welfare. The main analytical extensions of the basic WHM approach in this light include studies by Hung (1993) and Hartwick (1993) who incorporate stock effects in resource depletion. Johannson and Lofgren (1996) examine the use of green NNP as a cost-benefit rule. Aronsson and Lofgren (1998) examine the formal approach to

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NRA when there are imperfect markets, and Aronsson (1998) incorporates distortionary taxes. Weitzman has re-entered the literature looking at the impact of technical progress (Weitzman 1997) and interest rate uncertainty (Weitzman 1998) on his original result.[14]

These papers generally focus on deriving 'welfare equivalence' results. Recalling our distinction between welfare and sustainability, we note that a number of authors have also explored sustainability in resource-dependent economies within the WHM framework. Solow (1986) examined a Hartwick's Rule situation (Hartwick 1977), involving the reinvestment of all resource rents, to show the relationship between constant wealth and constant consumption. Hartwick has further contributed to this literature (Hartwick 1994, 1996).

Note that these models require specific assumptions to get sustainability results. In taking a more general interpretation of the WHM approach as linking income to wealth, and thereby providing a bridge between the SHS and Hicksian measures of income, caution needs to be exercised. Aaheim and Nyborg (1995) note that Weitzman's result does not reveal a feasible consumption level that can be maintained in perpetuity (as stated erroneously by, for example, Musu and Sinisalco 1996, p. 28; and Nordhaus 1999, p. 47). What it shows is the hypothetical constant consumption path that has equivalent present-value-of-welfare implications to the actual consumption path the economy is following. Neither consumption nor the capital stock are necessarily constant, which means that while Weitzman's result has a temptingly Hicksian flavour (income is a return to wealth), it does not match a consumption level to an underlying non-decreasing capital stock, nor to a constant future consumption flow.

A sceptical literature has arisen concerning sustainability in growth-theoretic models, in particular regarding the relationship between wealth and income. The thrust of this work is to show that, in general, it is unsafe to infer sustainability from a constraint about constant wealth (e.g., Asheim 1994, 1997; Pezzey and Withagen 1997). The sustainability interpretation of the capital-theoretic approach has already been criticised for relying too heavily on substitutability assumptions and on getting prices 'right'. This literature referred to in the present article is based on growth models of the sort associated with WHM analyses, in which case the assumptions of substitutability and prices reflecting optimal growth are built into the analysis. Even so, these authors present examples where increases in wealth at particular points in time are associated with falls in sustainable consumption paths.

[14] See also works by Rymes (1993), Hamilton (1994, 1996), and Vellinga and Withagen (1996).

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A prominent subset of the literature explicitly addressing sustainability, concerns using the growth-theoretic framework, is to do with the appropriate accounting procedure with exhaustible resources in an open economy context. To obtain a sustainable consumption stream from non-renewable resources requires reinvestment into produced capital in the closed economy as per Hartwick's Rule, which will be subject to diminishing returns. In the open economy, the possibilities are broader: investment may be in financial rather than physical capital, and diminishing returns may be irrelevant in the small country case. The literature here is recent, and there is yet to be a good synthesis of models and results. But in determining the optimal depletion path for the country's resource stock, the required level of reinvestment of rents and the appropriate adjustments to accounting procedures, the following issues stand out as important. The first and most obvious is conditions in the world resource market. The second is whether market power is held by the resource exporter in the world market. The third is the impact of resource depletion on returns in other asset markets. Finally, the appropriate treatment of capital gains in the national accounts turns out to matter. Conclusions about capital gains vary depending on whether authors view capital gains as endogenous (resulting from resource depletion itself) or exogenous; and (separately) whether they are stochastic or follow a predictable trend [see Usher (1994); Hartwick (1995); Asheim (1996, 1997); Sefton and Weale (1996); Brekke (1996, 1997); Vincent *et al.* (1997); and Klepper and Stahler (1998)].

Finally, analysts have used the forward-looking WHM paradigm to address the problematic issue of technical change. Both Nordhaus (1995) and Weitzman (1997) have attempted to model national income in a sustainability context with assumptions made about possible technical advancement. Turner and Tschirhart (1999) take the ambitious step of embedding national accounting issues into an endogenous growth model.

Dissent and critique

The WHM approach to defining and measuring income, and the idea that there is a useful welfare interpretation to national income, has been subject to question and challenge from a number of authors. Brekke (1994) and Usher (1994) criticise the real/nominal dichotomy in the WHM approach. While they make similar points, Brekke argues from practice, that statistical agencies measure real changes in a way inconsistent with WHM, while Usher offers a conceptual critique: that the proper measurement of growth (changes in income over time), raises index number issues suppressed by the WHM approach.

Aaheim and Nyborg (1995) offer several critiques of the underpinnings for NRA provided by the WHM models, not least the assumption of

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optimisation that is used to generate the results and interpretations. Global optimality is a strong assumption; moreover one of the motivating forces behind advocacy of NRA is the idea that there are serious policy issues arising from sub-optimality in natural resource use. Assuming optimality at the start comes dangerously close to assuming the important problems away.

Moreover, the neoclassical capital-theoretic approach is problematic to ecological economists and others who question the fundamental assumptions of capital substitutability. Questioning this assumption automatically brings into question the interpretation of any monetary aggregate index.

3.3 Discussion

This review of the motivations for, and conceptual foundations of, the NRA literature reveals several important tensions. The policy aims and objectives of NRA are often not explicitly expressed, and as a consequence, the underlying conceptual issues which the accounts are being used to shed light on are often vague. Are we constructing a welfare measure? A sustainability indicator? A resource management scorecard? Even the basic concepts, the definitions of income, are contested, or else blurred.

The economist's way to think of income is typically as a return to some underlying stock of capital or wealth. The key definitions of income presented so far have had this perspective in common, but important differences in interpretation should be noted. Schanz-Haig-Simons income, or Y_{SHS}, is interpretable as a return on actual existing capital (depending on the breadth of the definition of income, the capital stock may include produced, natural, human and 'social' capital), where Y_{SHS} may rise or fall over time as capital is accumulated or consumed. Hicksian income, Y_{Hicks}, has various specific interpretations but in general it may be interpreted as a return to wealth, where wealth may be defined as the value of existing capital, or else as the more abstract notion (as described by Hicks) of summed discounted future receipts. What matters is that the return measured by Y_{Hicks} is non-declining. In other words, the capital underlying the Y_{SHS} measure is actual available capital, however defined. The capital stock relevant to Y_{Hicks} is that amount of capital necessary for sustainable future consumption.

By contrast, the Weitzman–Hartwick–Maler version of income, Y_{WHM}, measures income as a return to wealth defined purely as the discounted value of future consumption, which may be in consumption-good units or utility units depending on the model. It stresses construction of a point-in-time welfare measure, where welfare is in present value terms. Being the 'stationary equivalent' of the return to wealth, it has no immediate

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sustainability interpretation, despite claims to the contrary in parts of the literature.[15] Where $Y_{Hicks,}$ as defined here, is a consumption-only concept, Y_{WHM} is explicitly consumption plus capital accumulation.

A different emphasis on adjusted accounting practices might arise from a perspective that stresses resource management (note that the Hamiltonian approach originally proceeds from the assumption that the economy is following an optimal trajectory, suggesting the resource in question is already being appropriately 'managed'). Using NRA to improve the efficiency of resource use is the stance taken by Clarke and Dragun (1989). In a contribution that predates the WHM literature, this different emphasis leads to different prescriptions regarding how NRA might be best applied, not to mention an increased degree of scepticism about how useful NRA might be as a resource management tool. They regard depletion as synonymous with depreciation only when there exists some underlying distortion affecting resource allocation. For example, they argue it is misleading to count deforestation as depreciation of natural capital when the land is to be used for agriculture, if the returns to agriculture are greater than the returns accruing to an intact forest. In such an instance, it is really asset substitution rather than depreciation, and if the market works efficiently, should represent a net improvement to the economy.

If it is accepted that a welfare measure is the goal, as per WHM, what comparisons between time and place can be drawn? Hartwick (1990) argues that NNP as constructed using the Hamiltonian is best suited for intertemporal rather than international comparisons. As already pointed out, several authors have criticised the index-number issues that arise in this context using this measure.

Two other perspectives will be briefly touched on before we move to the issue of official adjustments to the national accounts: that of the national accountants' and that of the ecological economists'.

The accounting profession, and the national accountants who have been informed as much in their work by accounting practice as by economic theory, see income rather differently. While they do prepare (in principle) balance sheets that relate asset stocks to income flows, the view of income that motivates the accounts is not as a return to wealth, but as a flow created by production, and reconciled within an accounting identity (the 'circular flow' of elementary textbooks). Questions of consistency in the accounts (maintenance of appropriate accounting identities including ability to reconcile stock and flow accounts) dominate questions of interpretation of

[15] That is, unless one defines sustainability in general terms as 'some implicit measure of the economy's generalised capacity to produce economic well-being over time' as Weitzman (1997) does.

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an aggregate monetary index in the minds of national accountants working on extending the SNA.[16] Bos (1997) is particularly forceful in drawing the distinction between economic and accounting approaches in the context of national income. He notes, for example, that market prices, which are typically given a normative (and often forward-looking) interpretation by economists, have no such normative role in the traditional national accounting paradigm. They are simply monetary weights used to aggregate various components of total output. Despite the stock-flow relationships in national accounting methodology, national income is fundamentally an atemporal concept, not a dynamic one as seen by Weitzman and others. National accountants, even those engaged in aspects of environmental accounting, are reluctant to move beyond the conventional core accounting relationships. As a result, there is little impetus at official levels to modify key aggregates like GDP. This is a theme of Section 4.

For many ecological economists, key assumptions underlying the NRA analyses considered so far are, while standard in welfare economics, not generally regarded as applicable to environmental problems, especially by those who adhere to the concept of 'strong sustainability'. Principally, any approach that endorses monetary measurement of natural wealth and comparison with other forms of wealth assumes that 'weak sustainability' holds. (So-called 'strong sustainability' is a more restrictive condition, where the criterion is a constant natural capital stock, the implication being that depletion of one form of natural capital must be matched by an increase in some other form of natural capital. See Pearce and Turner 1990; and Atkinson *et al.* 1997, Chapter 1, for detailed discussions of these concepts). The capital-theoretic approach to sustainability requires the assumption of complete substitutability between the relevant forms of capital, and the presumption that the 'prices are right', in the sense that all forms of capital are correctly valued in terms of their substitutability (where substitutability is judged according to their respective productivity.[17] For comments and critiques, see Common 1990; Victor 1991; Hinterberger *et al.* 1997; and Stern 1997).

[16] This raises issues of the definition of production, consumption and assets that will be touched on in the subsequent discussion of revisions to the current SNA.

[17] Other ethical assumptions (individualism, anthropocentrism and utilitarianism) underlie the NRA approaches discussed herein (these can be thought of as underpinning the 'consumer sovereignty' assumption highlighted by Dowrick and Quiggin 1998). The reliance on these assumptions becomes less strict as NRA approaches rely less on purely monetary measures.

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4. Official National Resource Accounting: Australia and elsewhere

> Developing augmented accounts must not come at the expense of maintaining and improving the current core national accounts, which are a precious national asset.
>
> (Nordhaus 1999, p. 46)

In this section we detail how the SNA has been adjusted to take account of the environment as part of the System of Integrated Environmental and Economic Accounts (SEEA). We also describe NRA undertaken by the Australian Bureau of Statistics (ABS). This is followed by a critical evaluation of official NRA activities.

We observe that questions of recalculating, and re-interpreting, national income in ways suggested in Section 3 are avoided by the maintenance of key definitions and accounting boundaries, and the use of distinct satellite accounts as an alternative to major changes to fundamental aggregates (attempts to produce actual augmented measures of national income are reviewed in Section 5).

The accounting boundaries employed in the SNA constitute the national accountants' definitions and classification of categories such as consumption, production, etc. Herein lies a key difference between many economic models used to analyse national accounting issues, and the accounting standards employed internationally. The issue is, in broad terms, that what accountants measure in the production and/or consumption categories is primarily defined by whether or not something lies within the 'market sector', that is, whether it is transacted in a market. Thus the market sector defines the 'boundaries' of what is conventionally included in consumption and/or production. In this way, accounting identities linking production to income are maintained.

By contrast, what economists think of as production or consumption is defined by the effect on output or utility, not on whether it explicitly involves a market transaction. Typically, the theoretical models used in the literature surveyed do not distinguish between market and non-market sectors, meaning economists sometimes overlook these boundary issues. One implication is that economists have typically been much more ambitious regarding the construction of augmented measures of social income, as evidenced by the studies surveyed in Section 5, than have national accountants. Official revisions to national accounting practice have, by contrast, been limited in their scope, avoiding fundamental changes to key aggregate measures.

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4.1 Revising the System of National Accounts

The SNA, introduced in 1968 by the United Nations Statistical Division (UNSD), is an internationally agreed framework (providing principles, concepts and classifications) that provides a consistent description of market based economic activity within an economy. Almost all countries undertake national accounting in the same way allowing national and international decision-making and country to country comparisons.

The SNA is composed of stock accounts (i.e., balance sheets) of national assets and liabilities, and flow accounts that measure transactions in the economy. The stock accounts show changes in wealth during an accounting period as a result of accumulation, depreciation and revaluation of assets. The flow accounts are frequently used to measure national income. Gross Domestic Product and the various derivatives like NDP are flow measures derived from national income. However, the SNA only takes account of economic activity in organised markets. Hence, the SNA is deficient: consumption of resources are treated as income instead of a reduction in wealth; economic costs imposed by degradation are unaccounted for; expenditure on pollution abatement increases GDP; and non-marketed services of the environment are excluded.[18]

Many nations are undertaking NRA exercises to adjust/supplement the SNA for environmental deficiencies. These activities started in the 1970s when, for example, Norway, France and the Netherlands initiated pioneering research, integrating macroeconomic and environmental policy, to ensure better long-term management of their natural resources (Alfsen 1996). During the 1980s the UNSD and the World Bank began to coordinate international efforts to modify the SNA to include the environment. These efforts led in 1993 to the SEEA and a significant number of national NRA applications. For example, the UNSD has supported resource accounting exercises in Colombia, Ghana, Indonesia, Mexico, Papua New Guinea and the Philippines, as well as OECD countries and the EU. Interestingly, the USA has not officially undertaken NRA since research was terminated by Congress for political reasons in 1993 (Hecht 2000). However, there have been calls for the resumption of research (e.g., Nordhaus 2000).

4.2 The Interim System of Integrated Environmental and Economic Accounts

The Interim SEEA incorporates environmental concerns in a number of ways:

[18] Milon (1995) provides a summary of environmental and natural resources coverage in the SNA.

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1. By segregating and elaborating all environment-related flows and stocks within the SNA.
2. By expanding asset accounts beyond 'economic assets' to include 'environmental assets' and changes therein.
3. By detailing impacts on natural assets caused by production and consumption.

The distinction between economic and environmental assets is central to the SEEA. Economic assets provide the economy with inputs in production and consumption, conferring economic benefits to the owner of the asset. Environmental assets yield environmental services such as waste absorption, habitat, flood and climate control. Within the SEEA, depletion and degradation of environmental assets is considered a cost to be accounted for in the production accounts. This is a fundamental change to the SNA where depletion and degradation of economic and non-economic assets are currently recorded as 'other changes in volume' in the asset (stock) accounts. The SEEA includes environmental depletion and degradation by measuring the change in value in asset accounts.

While the distinction between economic and environmental assets represents a clear departure from previous practice in the SNA, it is the only significant change to the SNA. The flow boundaries, production and consumption, have not been broadened to incorporate environmental flows or resource depreciation, leaving the core income and expenditure accounts largely unchanged. By adjusting the production boundary a fundamental accounting identity is broken, that between the value of income generated, total value added and the income used for the purchase of capital and consumption goods and services. Thus, those responsible for revising the SNA have resisted the pressure to 'green' the main monetary aggregates such as GDP. The core flow accounts are clearly defined by key accounting identities, providing interpretable economic magnitudes, and to alter these in fundamental ways is to sacrifice well-understood measures. Hence, the SEEA is pragmatic in that the internal consistency of the SNA is retained.

Instead of including monetary estimates of environmental damage and resource depletion in the conventional flow accounts, the approach has been to base the SEEA on disaggregated, issue specific 'satellite' accounts (United Nations 1999). The satellite accounts sit alongside the core accounts and can be integrated through balance sheets and other means. The satellite accounts fulfil several roles. First, they show the segregation and elaboration of all environment-related flows and stocks within traditional accounts. Second, they provide a link between the physical resource accounts with monetary NRA and balance sheets. Third, they help the assessment of environmental costs and benefits. Finally, they help to account for the maintenance of

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tangible wealth, and to elaborate and measure indicators of environmentally adjusted product and income.

Despite the apparent limited modifications to the SNA, developers of the SEEA emphasise its flexibility. To accommodate the breadth of NRA methodologies a modular approach has been taken with the SEEA.[19] Five versions of the SEEA are identified (United Nations 1999). Versions I, II and III only use physical information in their construction. Version IV introduces methods for estimating the (monetary) value of natural assets and costs of depletion. There are three forms of version IV. Version IV.1 uses market valuation according to the principles of non-financial asset accounting in the SNA. Version IV.2 uses maintenance valuation which estimates the cost necessary to sustain at least the present (or a feasible standard) level of natural assets. Version IV.3 uses various valuation techniques for estimating damage costs resulting from the loss of consumptive services of the environment. Finally, version V extends the production boundary of the SNA by reference to household production (consumption) and its impact on the environment and human welfare. Like version IV there are three forms of version V. All five versions of the SEEA reflect differing NRA objectives. However, all are formulated in a manner that maintains accounting consistency with the SNA.

To help implement the Interim SEEA, the Nairobi Group was established by the UN Environmental Programme in 1995, following requests made in Agenda 21 of the 1992 Earth Summit. In 1999 the Group produced a draft operational manual on selected modules of the SEEA as well as computer software to implement the SEEA.[20]

4.3 Recent revisions of the System of Integrated Environmental and Economic Accounts

A new version of the SEEA (hereafter SEEA–2000) is currently being finalised by the London Group and is due for publication in 2001. The London Group was formed in 1993 to provide a forum for sharing experiences of NRA with a view to revising the Interim SEEA and overseeing the development of SEEA–2000.[21]

[19] The IUCN provide a comparative study of nine NRA applications (see Hecht 2000). The United Nations (1999) and World Wildlife Fund web site (http://www.panda.org/resources/publications) also provide further examples of SEEA applications.

[20] This software is freely available at http://www.feem.it/gnee/seeahot.html

[21] The London Group has a web site (http://www4.statcan.ca/citygrp/london/london.htm) at which various draft chapters relating to SEEA-2000 are available.

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The SEEA–2000 will be a common framework to undertake NRA reconciling varied national exercises and experiences. For example, it can accommodate NAMEA (National Accounting Matrix including Environmental Accounts), a physical accounting framework developed by the Dutch and implemented in several countries (de Haan 1999). National Accounting Matrix including Environmental Accounts allocates environmental impacts, mostly emissions, to the economic sector generating them and juxtaposes them next to the conventional economic aggregates. It overcomes physical aggregation problems by converting all pollutants to a common unit based on the contribution to a particular environmental problem.

Although NAMEA is a popular compromise between conventional national accounting and ambitious revisions of monetary aggregates, it has not met with universal approval. Bartelmus (1999a) is critical of NAMEA on the grounds of timidity: he prefers more ambitious monetary adjustment, with prices being the common numeraire, giving the national accounts superior integrative capacity compared to physical aggregates like NAMEA. Bartelmus (1999b) is the main exponent of SEEA monetary NRA having undertaken extensive research in the Philippines. He estimated the Environmentally-adjusted Net Domestic Product (EDP)[22] that adjusts NDP by taking account of the costs and benefits of natural resource depletion, environmental-quality degradation and resource improvements. Bartelmus (1994) claims that an upward trend in EDP implies sustainable economic growth, but this is challenged by Dasgupta *et al.* (1995).

Another NRA exercise included within the revised SEEA is the data collection and measurement effort called SERIEE (European System for Economic Information on the Environment). These data measure environmental protection expenditure classified according to the environmental media or type of pollution/degradation. Many EU countries have been at the forefront of developing SERIEE. However, as we discuss in Section 5, the policy value and information contained within environmental protection expenditure accounts is unclear.

In summary, the SEEA–2000 is intended to yield a handbook of best practice in NRA. While not an international standard, it will as far as possible, detail harmonised and standardised approaches at the conceptual and practical level. Different sections of the handbook will deal with how to construct asset accounts (ie., balance sheets and accumulation accounts for natural assets) and physical flow accounts. The SEEA–2000 will also detail

[22] As we discuss in Section 5 there are other examples of where green GDP has been estimated. However, as an advocate of the SEEA, Bartelmus has undertaken these calculations strictly following the rules of the SEEA.

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Table 1 Australian Bureau of Statistics natural resource accounting research

Natural resource accounting activity	Research output
Balance Sheets	Net worth land, subsoil assets, forest and livestock \$1,580.5 billion 1989, \$1,687 billion 1991,\$1,669.4 billion 1992
SERIEE	Total national expenditure environment protection \$8.4 billion in 1995–96, \$8.6 billion 1996–97
Energy accounts	Measures of physical units energy bearing resources e.g. petroleum, coal, uranium and wood for years 1992-93–1997-98. Aim to use accounts in Input-Output model to examine emissions fuel
Fish accounts	Physical measure of fisheries production 1990-91–1996-97. No information on fish stocks
Mineral accounts	Physical measure of demonstrated resources 1985–1996. Detailed stock, production, and consumption accounts, and flow accounts
Forest accounts	Physical accounts being developed.
Water accounts	Measure of physical characteristics of water resources 1993-94–1996-97. Measure of supply, use and consumption by industrial and household sectors

Note: All information in Table 1 is available in various ABS publications or at the ABS web site: http://www.abs.gov.au

the types of valuation techniques that can be used to allow the valuation of environmental stocks, flows and costs.

4.4 The System of Integrated Environmental and Economic Accounts in Australia and the Australian Bureau of Statistics

The ABS has taken the SEEA seriously, actively engaging in several NRA exercises: balance sheets for selected resources, environment protection expenditure costs (i.e., SERIEE), energy accounts, fish accounts, mineral accounts, forest accounts and water accounts.[23] The key features of ABS NRA activity are summarised in table 1.

As table 1 highlights, ABS–NRA efforts have generally focused on physical measurement in satellite accounts. Although the balance sheet and the environment protection expenditure estimates present monetary estimates these are for market resources and activities and as such are captured already, albeit in a different form, in the conventional accounts.

[23] Oakley (1996) provides a useful summary of ABS research efforts. The ABS web site (http://www.abs.gov.au/) contains more detailed information about various accounts highlighted here.

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4.5 Assessing the System of Integrated Environmental and Economic Accounts

Conservative but flexible

The SEEA is arguably a conservative approach to NRA, in that its designers have resisted the urge to tamper with the core accounting relationships, instead using satellite accounts that contain physical rather than monetary information.

> [D]eveloping augmented accounts must not come at the expense of maintaining and improving the current core national accounts, which are a precious national asset.
>
> (Nordhaus 1999, p. 46)

The conservatism stems from the desire to build on the consistent accounting principles established in the SNA so that a systematic discipline is brought to the organisation of information. In principle, standardisation might be beneficial, but it is not a costless benefit of the system. If efficient data collection and examination requires marginal benefits to equal marginal costs it is unlikely that this condition will be satisfied by similar data collection exercises among various nations. Efficiency will almost certainly require differing degrees of data collection and use for different countries. Furthermore, simply relying on convention and convenience may yield a system that is incomplete and unable to address important environmental management questions because many goods and services are still beyond the scope of the accounts.[24]

There are examples of NRA that have extended the SNA beyond the boundaries of best practice as identified in the SEEA. Peskin (1989), advocated and employed ENRAP (Environmental and Natural Resource Accounting Project) that extended the production and consumption boundaries of the SNA. The trade-off inherent in this approach is that the consistency associated with the SNA no longer holds, but important environmental goods and services are included. Although United Nations (1999) acknowledged ENRAP, the reluctance by national accountants to embrace NRA practices as 'radical' as ENRAP can be traced to the desire to maintain accounting conventions.

However, the SEEA can also be considered flexible in that it provides a consistent framework for the inclusion of any number of resource and environmental issues. It is designed to be flexible enough for different countries to adapt their SNA to their own environmental and natural

[24] More fundamental ecological critiques of the SEEA are made by Holub *et al*. (1999), who highlight the incompatibility of economic and ecological scales, and the use of artificially generated data.

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resource circumstances. This has been achieved by designing the SEEA on a modular basis. A country can decide which modules it wishes to include. As a result there have been many varied NRA exercises (Peskin and Lutz 1993). The choice of modules available when implementing the SEEA is in many ways a reflection of the complex task in hand. Although the modular approach is practical, it allows for a diversity of approaches within the SEEA (e.g., NAMEA and SERIEE) and so it is (arguably) also a weakness. Although several countries can undertake SEEA consistent NRA, the resulting mix of modules may be different between countries, and comparisons between countries become meaningless.

Stock and flow accounts (balance sheets)

The SNA, and hence the SEEA, are designed around flow accounts that measure transactions within the economy and stock accounts that identify national assets and liabilities. As noted previously, changes have been proposed to the asset boundary, but not to the consumption and production boundaries. In effect, this means the stock accounts have been broadened but the flow accounts have been left largely untouched. The accounting imperative for this approach is that flow and stock accounts should be integrated to form a comprehensive system of accounts.[25] The information from flow accounts should be reconcilable with opening and closing stock accounts listing overall assets and liabilities. However, national accounting generally fails in this dictum, as changes in wealth are more easily calculated than total wealth. National income is thus calculated in isolation from any measure of national wealth.

The interest economists have in balance sheets relates to the capital-theoretic approach of environmental accounting with the intuitive appeal of viewing true income as a return to wealth. Well-prepared balance sheets will, in principle, serve as an indicator of whether or not we have achieved sustainability. As discussed in Section 3, constant wealth is a criterion by which sustainable (Hicksian) income can be defined and measured (Solow 1986; Hartwick 1994, 1996). Moreover, balance sheets may provide useful information on how the composition of wealth is changing over time: which assets are being built up and which depleted.

However, it is not clear if balance sheets have a compelling role to play in NRA. Questions exist about how robust the relationship between constant wealth and sustainable income is. In practice, difficulties arise in valuing the components of wealth accurately. For example, do prices reflect all the

[25] For a discussion of balance sheets and related issues of asset valuation in the SNA, see Harrison (1993), Milon (1995) and Bartelmus (1995).

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information necessary to draw useful conclusions about sustainability? Wealth is simply the sum of a series of products of price and quantity terms: if wealth at the end of an accounting period is equal to wealth at the beginning of that period, all we know is that one sum of price/quantity products is equal to another. Particular prices and quantities may well have changed, and it need not be the case that these changes are neutral on balance in terms of future consumption prospects.

El Serafy (1997) has also criticised the accounting for stock emphasis of the SEEA. He notes that if no country has been able to compile a comprehensive list of produced capital, how can they be expected to achieve this objective for non-produced capital? The focus on stocks results from a desire to measure environmental deterioration, yet if physical measurement is required, why the need to be constrained by the SNA? The SEEA is only an accounting (i.e., scorekeeping) framework. So, is the rationale that underpins the SNA an appropriate basis on which to formulate data collection for environmental management and policy tasks? Although SEEA provides a coherent accounting framework in which to collect data it is not clear if accounting consistency provides any resource management benefits.[26]

Finally, we note the publication of balance sheets for Australia (ABS 1995, see table 1). While these include natural resources in the national balance sheet, only the market values of resources traded within the market sector are included, rendering these invalid as proxies for a measure of 'national capital underpinning a sustainable level of income'.

4.6 Summary

There is extensive research activity advancing NRA, in particular the UN SEEA. However, there are many unanswered questions relating to the direction of current research efforts and the practical value of the SEEA. The desire for a new macro-indicator has not been met by the revisions undertaken thus far. Indeed there are few indications that matters will move in that direction despite the enormous outpouring of theoretical literature exploring the foundations of such measures (as presented in Section 3), or the applied literature in which revised macro measures are estimated for a variety of countries and regions (see Section 5).

[26] The data used to construct NRA is drawn from many sources. As Grambsch *et al.* (1993) observe diverse data sources are not necessarily consistent and care needs to be taken when pooling information sets, even if the information system is itself consistent.

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5 Theory in practice: What economists are doing

> If there is a common thread running through the literature on green accounting, it is that use of the environment and natural resources represents asset consumption, and that one of the key problems is that this is not reflected in the measures of income and product.
>
> (Atkinson *et al.* 1997, p. 49)

In Section 4 we examined official NRA activities. As we explained, national accountants frequently take a conservative approach to NRA as exemplified by the SEEA. In this section we examine how economists have undertaken NRA, some of which can be considered experimental in that some of the techniques and issues addressed have not been adopted or used in the SEEA. We do not go into specific detail about every study undertaken to date. Instead, we focus on the key themes that have emerged in the literature. Appendix A summarises key features of the more important economic studies in the literature to date.

Much NRA undertaken by economists stems from the adjustments proposed in the (capital) theoretical literature (albeit with differing degrees of rigour). We focus on the following five areas of adjustment: (i) non-renewable resource depletion; (ii) renewable resource depletion; (iii) non-market environmental benefits; (iv) defensive expenditure; and (v) other. As will become clear, there is little consensus in the literature about best practice in relation to how to make the proposed adjustments. The literature is piecemeal, contains many significant differences of opinion and it is still evolving without clear goals and objectives. This is maybe not surprising given the inherent confusion that we have identified in relation to income, welfare and sustainability.

5.1 Non-renewable resource depletion

Significant effort has been directed at non-renewable resources. This is probably due to two factors: (i) 1970s 'limits of growth' arguments where depletion of non-renewable resources was perceived as a pressing threat to sustainability; and (ii) many developing nations have (arguably) excessively high rates of consumption, thus depleting resource stocks too rapidly.

The principal approaches to account for the depletion of non-renewable resources are the Net Price (Depreciation) (NP) method (Repetto 1988; Hartwick 1990; Maler 1991) and the User Cost (UC) method (El Serafy 1989). We briefly explain both methods and examine how they have been used in practice.

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Net price (depreciation) method

The NP formula, synonymous with Repetto (1988) is derived from a dynamic optimisation model where efficient resource pricing (i.e., Hotelling's Rule[27]) is assumed. Repetto argued from the standpoint of comparing wealth and income. In the SNA with manufactured capital, if current capital is depleted in the course of generating current income, then a depreciation entry is calculated to offset the reduction in capital (or wealth). By treating the resource as a form of capital, then depreciation (i.e., depletion of the resource stock) should be offset against current income generated by its extraction. Net price is calculated as follows:

$$NP = (P - MC)Q \tag{6}$$

where $(P - MC)$ is price minus marginal cost and Q is the net quantity extracted per year, the difference between resource depletion and discoveries. Ideally, NP equates to the Hotelling rent accruing to the owner of the resource, such that the expected rate of growth of the unit rent would be equal to the discount rate.

The NP approach is consistent with growth-theoretic models (Hartwick 1990), and with national accounting procedures, in that it allows for the computation of a capital consumption allowance consistent with a net product measure. Levin (1991) and Landefeld and Hines (1985) endorse the use of measuring depreciation based on a NP measure and they go on to operationalise accounting procedures for measuring depreciation using this approach. Consensus on the appropriate treatment of discoveries is also not as settled as the previous discussion suggests.[28]

Despite frequent use, the NP method is subject to criticisms. First, the suitability of empirical applications of Hotelling's Rule is debateable (Young and da Motta 1995). Even if the use of Hotelling's Rule is accepted, average rather than marginal cost is frequently used in estimation. Hartwick (1990)

[27] Hotelling's Rule states that as the price of a resource rises, the rent per unit of resource extraction grows over time at a rate equal to the rate of interest.

[28] Authors such as Levin (1991) and Butterfield (1992) approach accounting for exhaustible resources from a national accounting perspective rather than a growth-theoretic one. Regarding resource discoveries, they make similar suggestions for using satellite accounts to record resource stocks as 'inventories' to be brought into the productive sphere. Butterfield is critical of treating resource depletion as akin to capital consumption (as is El Serafy; see the discussion on User Cost) but he does not support El Serafy's User Cost approach. Diaz and Harchaoui (1997), like Butterfield, base their treatment of exhaustible resources on Canada's accounting framework, and derive depletion adjustments that diverge somewhat from the WHM prescription, and that have implications for previous productivity growth estimates for mining industries.

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argues that the use of average rather than marginal cost to measure depreciation results in an overstatement of depreciation. Dasgupta, Kristrom and Maler (1995) counterargue that average costs may be a useful approximation in the case of a heterogenous resource (e.g., timber) and an 'innocuous simplification' where oil is concerned. Second, asset revaluations and discoveries, especially for sub-soil assets, give rise to changes in the value of the stock that can exceed depletion producing large oscillations in the adjusted measure of NNP. Third, El Serafy (1989) is critical of treating natural resources as analogous to produced capital. As he and Neumayer (2000a) observe, with the NP approach, resource depreciation just balances out against the income generated by any current extraction. All proceeds from current extraction are by definition capital consumption so that net income is zero (Hartwick 1990). In terms of national income, it is as though the resource never existed.[29] El Serafy argues that this is misleading, and suggests we think along Hicksian lines.

User cost

In thinking along Hicksian lines El Serafy (1989) proposes that current proceeds of extraction be split into two components. First is true income (the value added from resource extraction) and second is the residual, being that amount that would have to be reinvested in order to generate an ongoing flow of income equal to the first component. It is as if the entire resource stock were sold off and the proceeds reinvested into financial assets yielding an ongoing return. That is, from revenue R, let (true) income be X and the residual $R - X$ which is calculated as follows:

$$R - X = R/(1 + R)^{N+1} \tag{7}$$

where R is the discount rate and N is the remaining life of the resource measured in years. If investing $R - X$ generates a stream of revenues equal to X, then X is true income and $R - X$ is the UC associated with the resource depletion. Note that the reinvestment does not actually have to occur. The accounting principle is simply that, whether or not $R - X$ is reinvested, only X is true value-added to the economy from current resource extraction, and the $R - X$ is what should be reinvested if we are interested in Hicksian income.

Like NP, UC has been criticised on conceptual grounds. First, the treatment of rent expectations is unrealistic. Both unit rents and extraction levels are assumed to remain fixed. This implies that UC estimates will be constant while prices and extraction costs vary over time. In related

[29] This result holds only if there are no diseconomies.

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fashion, Dasgupta, Kristrom and Maler (1995), among others, have criticised the UC approach for making ad hoc assumptions regarding depletion patterns, the choice of the discount rate used and the length of the depletion period. It can be counter-argued that this 'ad-hocness' criticism can be overstated: El Serafy's method, like any, generates an approximation to some 'true' underlying measure. His procedure is updated in every accounting period, so a particular set of assumptions is not rigidly adhered to over time. The question must be, which measure (NP, UC, or another) yields the most economically useful figures, given that each is likely to contain errors with respect to some ideal measure. We note that in theory, the two measures (NP and UC) are theoretically reconcilable (Hartwick and Hageman 1993).

Second, the UC method confuses an 'income' measure with a 'product' measure according to Butterfield (1992). By insisting that 'user cost' does not measure 'capital consumption', and that therefore, gross rather than net product should be modified, El Serafy's method violates the product/income accounting identity. A devil's-advocate position might be that unmodified GDP should be computed according to the usual accounting restrictions, and GDP as modified by UC calculations should be presented as a more meaningful measure of sustainable income.

Net price and user cost applications

The seminal application of the NP approach is found in Repetto *et al.* (1989). The authors incorporated monetary measures of depreciation of key natural resources (timber, minerals and soil) into headline economic indicators drawing strong conclusions about the sustainability (or otherwise) of rates of growth in resource-dependent countries, observing significant declines in aggregate measures of income as a result of resource degradation. It was the strength of the results derived that drew so much attention to the idea of adjusting conventional measures of macro economic performance. Repetto and collaborators also carried out similar applied research in Costa Rica and the Philippines (Solorzano *et al.* 1991; Repetto 1992).

There have been many applications comparing and contrasting the results derived by both methods (e.g., Foy 1991; Winter-Nelson 1995; Young and da Motta 1995; Liu 1996, 1998; and Common and Sanyal 1998). These studies draw attention to the divergence of the results obtained using the alternative approaches. For example, Young and da Motta (1995) found that because the NP method includes a valuation of the known reserves in its calculation, estimates are volatile through time:

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> The erratic results obtained from the net price approach are a consequence of its main conceptual flaw (ie., both computed output and income depend on variations in reserves).
> (Young and da Motta 1995, p. 125)

Young and de Motta argue that the UC approach is to be preferred in practice. Liu (1996, 1998) also found significant differences, qualitatively and quantitatively, between the UC and NP methods. Liu (1996) concludes that the NP method yields 'erratic and unreliable figures for coal depreciation' (p. 180). However, to reconcile the impact that unanticipated discoveries can have on the NP measure it is possible to treat them as increases in wealth as opposed to income that directly impact on GDP.

For Australia, Common and Sanyal (1998) used ABS data to calculate the NP and UC measures of asset depreciation for non-renewable mineral resources. They found that their estimates for each method differed significantly and led them to conclude:

> … numbers which purport to measure the depreciation of non-renewable resources should be treated with healthy scepticism.
> (Common and Sanyal 1998, p. 29)

Neumayer (2000a) makes a similar point when re-examining research carried out by the World Bank (1997) on sustainability. The Bank measured Extended Genuine Saving II[30] that includes estimation of resource rent calculations. Neumayer (2000a) generated significantly different conclusions by using the UC method as opposed to a variant of the NP method. The World Bank argued that North African and Middle Eastern countries are unsustainable whereas Neumayer provided results to the contrary.

Many analysts still opt to use the NP method. For example, Crowards (1996) estimated NP to examine resource depletion in Zimbabwe, making reference to the SEEA (United Nations 1993) to support this choice. Bartelmus (1999a) also favours the use of the NP approach, although he does note that the UC approach can be used for sub-soil assets (i.e., minerals).

5.2 Renewable resource depletion

Renewable resources are treated similarly to exhaustible resources with an additional term allowing for the regeneration of the resource. Instead of

[30] The Extended Genuine Savings II measure is adapted from the Genuine Savings Index (Pearce and Atkinson 1993). It measures whether savings divided by income minus the value of depreciation of man-made and natural capital both divided by income is positive or negative.

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deducting the resource rents, an addition to the net growth of the renewable resource stock valued at the rental rate is included. It is possible to conceive of a steady state in which the resource stock is not being depleted, and only the net harvest is being consumed (in which case the addition would be zero).

From a sustainability point of view, a steady state situation with respect to renewable resources is desirable. However, several possible steady states with different equilibrium stock levels and harvest rates may exist. The efficient stock size may be less than the current stock, meaning according to welfare criteria the stock should be diminished. This may violate a sustainability constraint defined on resource use. If it is truly efficient, this strategy (over-harvesting now until a lower-level steady state is achieved) will increase sustainable income to society if the resource rents are reinvested into better performing assets but may reduce a net product measure incorporating depreciation of natural capital (Clarke and Dragun 1989). This is a simple example of why NRA may be a poor resource management tool.

Two renewable resources frequently examined in the literature are forestry and soil depletion (erosion).

Forestry

The evaluation of changes in forestry and woodland assets are calculated as:

$$(p - MC)(MAI - L) \tag{8}$$

where p is the per unit price of harvested wood, MC is the per unit marginal cost of harvesting, MAI is the mean annual increment in wood and L is the level of harvesting.

Examples of measuring forestry and woodland contribution in the literature are provided by Hultkrantz (1992), Adger and Grohs (1994), Crowards (1996) and Vincent and Castaneda (1997). Vincent and Castaneda estimated rents for roundwood (logs, pulpwood and fuelwood) for 14 South East Asian countries between 1970 and 1992. Unlike other studies Vincent and Castaneda first estimated total rents and then converted them into Hotelling rents following Vincent *et al.* (1997) as follows:

$$\text{Hotelling Rent} = \text{Total Rent} * (1 + \beta)/[1 + \beta(1 + i)T] \tag{9}$$

where β is the elasticity of the marginal cost curve, i the discount rate and T the numbers of years until resource exhaustion. Following El Serafy (1989) T can be estimated for both non-renewable resources and renewable resources. For non-renewable resources:

$$T = S/H \tag{10}$$

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where S is the current stock and H is the amount harvested. For renewable resources:

$$T = S/(H - G) \tag{11}$$

where G is growth. If extraction equals growth then T will tend to infinity and the resource is never exhausted. Vincent and Castaneda then compared their estimates of total and Hotelling rent to GDP (at market prices). The importance of their findings is that although per capita total rents were greater in 1992 than 1970 only in Papua New Guinea did rents exceed 10 per cent of GDP. They also found that all countries saved sufficiently to offset the depreciation in the natural assets as Hotelling rents were much smaller than gross domestic savings for all years. These findings are in keeping with the optimistic results reported by many previous resource accounting studies.

As noted earlier, Clarke and Dragun (1989) observe that forestry resource depletion will in many cases yield a new asset: agricultural land. The income earning potential of this land is currently ignored in NRA calculations and the net change in asset value need not be negative. Agricultural land could well be a more valuable asset. This is an example of asset substitution being counted as asset depletion.

Soil erosion

In NRA applications the cost of soil erosion relates to on-site costs, not the off-site costs. Methods of adjustment have been concerned with estimating either productivity decline or the cost of maintaining the level of soil quality at the beginning of an accounting period. To measure these values two methods have been used:

1. Productivity change – measures the change in value of resource rents as a result of soil erosion. This technique requires that a hypothetical level of production is identified so that the difference between the level realised can be estimated.
2. Replacement/maintenance cost – measures the cost of returning an asset to the existing level of quality observed at the start of the accounting period. This approach uses substitutes in production to proxy environmental damage. Replacement costs are those costs that could have been avoided if appropriate technologies or protection measures had been applied during the accounting period.

There have been a number of applications of the productivity loss approach (e.g., Adger and Grohs 1994; Whitby and Adger 1996; and Vincent and Castaneda 1997). Motivation for using the productivity loss approach for soil erosion can be found in the following quotation:

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> If observable market prices are not available or not representative, a discounted flow of additional or foregone net rents of land due to quality changes (including soil erosion) has to be calculated.'
>
> (United Nations 1993, p. 61)

Therefore, the reason for the adoption of this approach in many NRA applications is that the resulting calculations are consistent with the SNA in that they relate directly to hypothetical income.

Are these approaches consistent with the economic analysis of soil erosion? The productivity loss and maintenance cost approaches are problematic as they ignore price and substitution effects. Chisholm (1992) also argues that there may be an optimal rate of soil erosion. Indeed, the private rate of soil erosion may differ from the socially optimal rate, as farmers will only be concerned about on-site costs. Soil is only one input into the production process and to assess its optimal use correctly we need to simultaneously take account of the decisions about the use of other inputs and, for that matter, output prices.

Another reason to be circumspect about the usefulness of these approaches to valuing soil erosion is that in developed economies there will be a rural land market, which although likely to be thin, will yield market prices that reflect quality of land as a result of degradation. It is therefore questionable if productivity loss (or for that matter maintenance cost) estimates are necessary. Clarke and Dragun (1989) make a related point by arguing that resource exploitation in a developed country is typically a property rights issue. The failure to enforce property rights leads to resource depletion. However, before resource depletion can be identified it is necessary to identify the underlying externality. If there is no externality and resource use results from profit maximising behaviour, then should soil erosion, for example, be included in NRA calculations?

Finally, the off-site damage effects of soil erosion can involve significant costs and most NRA studies ignore these. Exceptions are Young (1993) and Golan *et al.* (1999). Young simply assumed off-farm costs in Australia to be 50 per cent of productivity losses. The crudeness of Young's calculations illustrates the lack of data on off-site soil erosion costs in Australia. Golan *et al.* use estimates derived by Ribaudo (1989). Although the available information on the off-site costs of soil erosion is small and dated, the magnitude of the costs incurred is large and as such it seems to be inappropriate to ignore these costs.

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5.3 Non-market values

As noted in Section 4, version V of the SEEA includes non-market environmental benefits such as amenity value. However, practical applications of the SEEA do not pursue this extension. Most focus on natural resource depletion and ignore environmental benefits. This can be explained by the fact that adjustments based on non-market environmental benefits yield inconsistent adjustments to the SNA in that they require the production and consumption boundaries to be changed. Doubts have, therefore, been cast about the validity of using indirect methods to estimate non-market values that are then included in the national accounts (Bartelmus 1999a, b). Furthermore, contingent valuation, for example, includes a measure of consumer surplus when evaluating willingness to pay, but measures of consumer surplus are by definition excluded from the national accounts.

To enable internally consistent SNA adjustment Bartelmus (1999a, b) argues that the maintenance cost approach needs to be employed. As has been observed, in relation to assets like wilderness, habitat or biodiversity:

> The calculation of 'option' or 'existence' values of these assets, which are not traded in markets but for availability individuals may be willing to pay, is hardly applicable in national accounting.
>
> (Bartelmus 1999b, p. 163)

This is important as it diminishes our ability to be able to interpret within the context of the SNA, at least, many existing NRA studies undertaken by economists (e.g., Peskin (1989); Grambsch *et al.* (1993); and Whitby and Adger (1996)). However, there appears to be less concern on the part of economists to produce estimates that are SNA consistent. Instead it is the policy relevance of the estimates or the desire to measure welfare that motivates research.

Peskin (1989) instigated the ENRAP that aims to measure the environment in monetary terms. Environmental and Natural Resource Accounting Project includes information on non-market environmental services and damages, as well as the depreciation of environmental assets such as minerals, yielding modified income aggregates. Examples of ENRAP include a study of Chesapeake Bay in North America by Grambsch *et al.* (1993). A particular feature of this study is that many of the non-market goods and services are consumed directly by households, and they are evaluated using contingent valuation. The study presented modified (Chesapeake) GDP estimates that were only marginally greater than the conventional measure meaning that net benefits from the environment previously unaccounted for are relatively small. A more recent application in the Philippines (Peskin and Delos Angeles

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2001) compares and contrasts results for ENRAP and SEEA. Like Grambsch *et al.* (1993) Peskin and Delos Angeles (2001) find that ENRAP yields results that are very different to the SEEA but not that different to conventional economic measures. They attribute these differences to three main reasons. First, SEEA has higher estimates of natural resource depreciation from using the NP approach; second, SEEA excludes positive environmental asset services such as amenity value; and third, SEEA does not take into consideration household firewood production.

The findings of Peskin and Delos Angeles (2001) have important implications about the claims that conventional GDP or NDP overestimate true economic performance. Empirically the inclusion of non-market values in these case studies balances out many of the costs associated with natural resource use so that the net effect is minimal. The associated questions about what adjustments need to be made, can only be answered by explicitly stating what it is we wish to measure, which, as previously noted, is a vexed issue.

Apart from issues of SNA consistency there are many questions that can be raised about the reliability and meaning of estimates derived using techniques such as contingent valuation. For example, there is the problem of aggregation of values based on direct methods. Measures of willingness to pay (accept) are frequently invariant. That is, no matter how precisely the environmental asset in question is defined, benefit estimates frequently embed broader environmental values. It is highly likely that there may well be a degree of double counting that occurs when aggregating several non-market values leading to an upward bias in benefit estimates. Could it be the case that the ENRAP results are subject to inflated benefit estimates and that this diminishes the real environmental costs incurred by the economy? Another possible source of bias is that many of estimates that are used are taken from 'related' studies. The practice of benefit transfer is fraught with concerns relating to consistency, meaning and reliability.

5.4 Defensive expenditures and environmental damage

Many of the problems that are inherent in including non-market benefits in NRA are also encountered when dealing with environmental damage and defensive expenditure. We delineate these two possible reasons for making adjustments to clarify some of the confusions in the literature.

Defensive expenditure

Defensive expenditures involve purchases of goods or services designed to ameliorate the effects of a worsening environment. Currently, these expenses count as final demands and thus add to national product despite not being

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welfare increasing, but rather disamenity-offsetting. But, defensive expenditures are problematic from the point of view of adjusting the national accounts. First, some expenditure can be viewed as defensive or preventative. Buying food defends us from hunger, buying medicine prevents sickness, and so on (Peskin and Lutz 1993). However, the important distinction is to do with the disamenity being offset by the expenditure in question. If the disamenity is a direct result of economic activity that enters as a positive item in the national accounts (such as industrial production), then it is intuitively sensible to regard any offsetting expenditure as an appropriate deduction. In contrast, expenditure on food to prevent hunger is defending against a state that would result regardless of current economic activity. Second, if pollution and environmental damage were (hypothetically) accounted for directly and correctly, then deducting defensive expenditures would double count the value of the disamenity.

Following WHM, defensive expenditures should be regarded as intermediate rather than final expenditures and deducted from income, but only after the underlying flow of environmental services has been included, unless actual damages can be estimated in which case they should not be deducted (Maler 1991).[31] However, there is a difference of opinion here regarding consistency with the SNA. Bartelmus (1999b) argues that deductions are methodologically questionable. Deducting defensive expenditure means that the resulting measure will be based on welfare judgements and this requires an arbitrary change to the production boundary of the SNA.

There are other more practical concerns regarding defensive expenditures such as jointness of production. A firm could invest in new technology for productivity gains, not necessarily because it is cleaner. The new technology may yield a reduction in pollution but this is only an indirect outcome. In this case how much of the expenditure should be apportioned to the environment? Another problem relates to defining actions as defensive. In the case of landscape protection it can be argued that payments to farmers are to prevent further landscape degradation (Adger and Whitby 1993), but it is possible to argue that the payments are for the production of the landscape that is being consumed by society. Depending on the perspective taken, such expenditure may be interpreted as productive or defensive.

A consistent approach to dealing with defensive expenditure is provided by Golan *et al.* (1999). They use a Social Accounting Matrix (SAM) to examine the impact of groundwater contamination from cotton production in California. The use of a SAM to focus on the cost of externalities on

[31] Vanoli (1995) examines defensive expenditures from a national accountant perspective, where interpretation according to accounting consistency dominates interpretation according to economics.

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welfare has many appealing features. They do not deduct environmental defensive expenditure but instead examine the distortions in the economy that result from the underlying externalities highlighting instead how the economy would have performed in the absence of these distortions. Bartelmus (1999b) proposes similarly that Input-Output (IO) analysis be used to explore how changes in environmental expenditure affect production structures, employment and export competitiveness.

Environmental damage

The treatment of environmental damage is ambiguous in the literature. For example, Peskin (1989) argues that negative externalities should be deducted from GDP. Alternatively, Bartelmus (1999a, b) proposes that environmental damages be deducted from NDP. Hamilton (1994) attempts to reconcile this literature using the WHM framework, arguing that environmental services be first added to NNP and then pollution deducted (valued at the marginal cost of abatement) and then finally environmental regeneration added. Hamilton's proposal is sensible in that it is the net effect of environmental damage that adjusts NNP. Hamilton also shows that the marginal cost of abatement is the appropriate way in which to measure reductions in welfare from negative externalities. For this reason he argues that (defensive) expenditure based approaches to valuing environmental damage are conceptually sound.

Given inherent difficulties in damage cost estimation the method frequently used in the literature is the maintenance cost approach. The maintenance cost approach measures those costs that could have been avoided if the appropriate technology or production system were in place. In using this approach it means that costs can be allocated to those who cause the pollution (i.e., the polluters-pays principle) yielding a measure that relates to the emission tax or charge that would be set to yield a level of pollution. A practical example of the maintenance cost approach is provided by Grambsch *et al.* (1993) who estimate air and water pollution damages based on the benefits derived from attaining target reductions.

5.5 Other

Open economy

Most NRA studies implicitly assume that countries operate in isolation from each other, all externalities are internalised and there is no trade. However, for some external impacts of economic activity there are cross boundary effects that cannot be internalised within a single country and there is also trade in marketed commodities. To account for trade Proops and Atkinson

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(1996) have suggested that each economy be viewed as a sector in a single global economy. Using IO analysis they estimated resource depreciation based on domestic and export demand. Common and Sanyal (1998) employed this method to examine how NP and UC estimates for resource depreciation were affected in Australia. They found that the differences taking account of trade are far smaller than those that exist between the different techniques.

In an open economy setting, a country will be a price taker for many natural resources. Given that international commodity prices are very volatile, an important component in the value of a resource stock may be capital gains from price fluctuations. Vincent *et al.* (1997) developed a method that allows the calculation of NP that takes into consideration capital gains in a consistent manner. They re-examine the petroleum data for Indonesia used by Repetto *et al.* (1989) and find that the Hotelling rent estimates indicate that Repetto *et al.* underestimated the prospects for sustainability in Indonesia.

Regional natural resource accounting

The construction of regional accounts has been examined by Prudham and Lonergan (1993a, b), who raise the issue of spatial delination. There is a tension here between using either biophysical or socio-political boundaries. In the literature to date the choice of region seems to be driven by socio-political boundaries, although this is probably influenced by the availability of data. For example, both Foy (1991) and Grambsch *et al.* (1993) examine regions in the US using data generated by the Bureau of Economic Analysis to construct Gross State Product (GSP). An alternative approach used by Vincent (1997) and Hanley *et al.* (1999) is to take aggregate data and divide it between the regions using regional shares of GDP.

What do such regional measures mean, and how should they be interpreted? Vincent (1997), for example, found that adjusted NDP for Malaysia grew and as such the economy could be viewed as being sustainable. However, for the regions, he found that the Borneo states had not grown sustainably but the Peninsula had. Issues of whether these estimates really measure sustainability aside, at what level should we assess sustainability? This is the same question that Whittaker (1997) asked of Whitby and Adger (1996) in relation to sustainability of the UK land use sector. If natural and man-made capital are assumed substitutable, what of substitution across regions? Is there any reason to be concerned about a single region or regions as long as all regions in aggregate are sustainable?

In undertaking regional NRA we need to be explicit about how the estimates derived relate to the objective in mind. If sustainability is the

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motivation then we need to ensure that the definition of sustainability relates to the region of study. Furthermore, regional accounts should allow for flows of goods and services both in and out of a region and as such, open economy models can inform how to capture these effects.

Aggregate sustainability studies

Many studies referred to thus far have been aimed at sustainability measurement, in what are broadly capital-theoretic terms: by measuring total depreciation of produced plus natural capital, the intention is to produce a measure that (in principle) approximates sustainable income. The serious difficulties with this interpretation (highlighted in Section 3) notwithstanding a number of studies, many of developing countries, of depreciation-adjusted national product have claimed to have produced sustainable-income measures.

In the developed country context, some studies have gone somewhat beyond conventional NRA-style adjustments, although remaining largely underpinned by neoclassical 'weak sustainability' arguments. Nordhaus (1995) and Thampapillai and Uhlin (1997) both examined the United States of America, neither revealing it to be clearly unsustainable. Thampapillai and Uhlin provide evidence of 'environmental efficiency' improvements over their period of study, while Nordhaus uses a generalised WHM approach including factoring in anticipated technical change to argue that investments in knowledge capital will be at least as fundamental for sustainability as investing in environmental capital.

Another variant on the 'weak sustainability' theme is the Genuine Savings measure of sustainable income (Pearce and Atkinson 1993), comparing aggregate (national) savings to aggregate depreciation on capital. In their calculations for 18 countries, Pearce and Atkinson find that the developed countries satisfy sustainability while the underdeveloped ones do not. Hanley *et al.* (1999) assess Scotland's sustainability using the Genuine Savings criterion, and find that while it did not satisfy sustainability, there was a gradual trend towards sustainability from 1985 to 1993.[32]

[32] This contrasts with the results presented in an 'Index of Sustainable Economic Welfare' (ISEW) in the same study that consistently declined over the period of interest. Indexes of Sustainable Economic Welfare are aggregate indicators that go well beyond national accounting principles and 'weak sustainability' underpinnings, where the indicator is adjusted in ad hoc fashion for factors such as income distribution. As such, they are beyond the scope of this study. But on aggregate sustainability indicators, see Hanley (2000).

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6. Conclusions

> We cannot explain why such firmly argued proposals as natural resource accounting seem to have received so little attention by mainstream resource economists. It may be that additional research in welfare economics is necessary before natural resource accounting procedures can be operationalised.
>
> (Clarke and Dragun 1989, p. 28)

Since the above comment was written, much research on the theory, implementation and application of NRA has been forthcoming. Natural resource accounting has also been brought explicitly onto the policy agenda, by the development of the SEEA and a vast array of country-specific exercises, providing renewed purpose to reviewing the usefulness of this approach. In fact NRA is revealed to be an umbrella term encompassing a wide variety of approaches, with the varied intent of (for example) improving the measurement of standards of living, improving natural resource management and reorienting long-term growth and development strategies.

In reviewing the NRA literature, one may choose to focus on particular aspects: the theoretical framework; methods employed and results arising from applied studies; and the evolving approach to official national accounting. One might even sketch key points from each of them and attempt to draw broad links between them (an approach adopted by Dasgupta *et al*. 1995). However, to provide a detailed overview of all these elements is not only difficult, but reveals the fragility of the interconnections between theory, application and official practice.

There are several sources of tension that emerge in our survey: differences among economists, differences among national accountants and differences between economists and national accountants. Examples of differences between economists include questions as fundamental as whether the principal focus should be on measuring (changes in) well-being (over time or across space?) or quantifying sustainable consumption and capital formation. Examples of differences between national accountants include fundamental questions about definitions of key accounting aggregates (consumption, production, capital) as well as appropriate valuation techniques. Differences between economists and national accountants reflect not just analytical issues but fundamental differences in paradigms. Income in the economic sense typically reflects a dynamic stock-flow relationship while in the national accounting sense it reflects an atemporal aggregation of components designed to conform to the appropriate accounting identities. These differences are then reflected in recommendations regarding adjustments and the interpretation of the resulting aggregates.

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Given the degree of tension identified in this review, what is remarkable is that, at first blush, there seems to be a fair amount of cohesion and agreement in the literature. It is true that a critical literature has appeared concerning everything from conceptual issues to application to policy: examples include Noorgard (1989); Aaheim and Nyborg (1995); Lintott (1996); and Mamalakis (1996). There is also explicit disagreement among practitioners about specific methods (UC versus NP, and maintenance cost versus productivity-based measures, just to cite two obvious examples) so we do not mean to imply that all is harmonious.

However, in our view, the field of NRA, particularly as viewed through summary treatments, is typically presented as exhibiting the usual degree of tension, disagreement and ongoing debate at the margin as any other analytical area, but with a solid consensus regarding its core elements. We believe this is misleading. Serious tensions at the very heart of the paradigm are insufficiently recognised in general discussion of the topic. One factor contributing to this is that the fundamental differences between economic approaches and those employed by national accountants are masked by similar terminology, as though when people talk about income, consumption, capital and so on, they all mean the same thing and agree on what is meant.

The discussion in Section 2 highlighted not only the lack of consensus on key underlying issues of measurement, but that some authors seemed unaware of this lack of consensus. The two obvious dimensions, welfare and sustainability, were discussed, with the distinctions between them highlighted. Moreover, the generality of these concepts (welfare and sustainability) were emphasised, noting that there are particular model-specific interpretations and definitions. However, it is not common practice for analysts to clearly specify a particular objective up front and then derive the specifics of their approach and results from that definition. Yet a focus on either welfare or sustainability measurement will have different implications for the adjustments made for resource depletion or environmental change.

As argued in Section 3, even a concept as fundamental as income is open to various interpretations. Hicks' famous discussion in fact presents a series of definitions and he laments that all of them are inadequate approximations to the ideal but unmeasureable 'central criterion'. Yet modern economists tend to talk of something called 'Hicksian income' as though it was clearly defined, well-understood and within the realm of measurability. The difficulty of reconciling *ex post* income concepts with *ex ante* ones was well-recognised by Hicks, but is rarely acknowledged in modern discourse. Moreover, the concept of income as presented by national accountants is based on accounting identities constructed to provide a measure of current production, not in economic terms as a return to wealth.

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The default philosophy in many applied papers, such as those covered in Section 5, appears to be to adopt a simplified capital-theoretic approach whereby a suitable measure of net domestic/national product is taken to be compatible with both (Hicksian) economic principles and national accounting practice. (The caveat being that all the appropriate elements of capital depreciation are included and satisfactorily measured.) This is one reason why careful distinctions between welfare and sustainability are not always maintained: if NDP, appropriately defined, is regarded as a suitable approximation to Hicks' *ex ante* measure based on sustainable consumption, then it can be argued that what is being measured is a consumption annuity or, put another way, 'sustainable economic welfare'. In these circumstances, welfare and sustainability coincide. The irony is that the very approximations that mask important differences between distinct concepts of income simultaneously blur the important distinction between welfare and sustainability.

The main problem is that the main economic concepts of income are appropriate for steady-states, yet these concepts are imposed on growing economies. Some authors (Usher 1980) treat the concept to be measured as if it arises in an economy in a steady-state. The Weitzman (1976) approach (interpreting income as the Hamiltonian function), by contrast, treats income as an explicitly dynamic concept, but this is not consistent with the fundamentally atemporal nature of national accounting measures of income. Moreover, the assumptions underlying the Hamiltonian approach are restrictive and introduce their own potential problems, highlighted in Section 3.

The applied studies under review here are not only open to question for the vagueness of their basic theoretical underpinnings (relating to income, welfare and sustainability). More specific problems arise. Key technical assumptions and methods differ from study to study, even when the studies involve similar questions or environments. Explicitly comparative studies, such as Common and Sanyal (1998) for exhaustible resources, and Hanley *et al.* (1999), for sustainability, show that empirical results (and policy implications!) can change significantly when different measures and methods are used.

Moreover, most NRA and sustainability studies of this nature utilise key assumptions that drive their results, namely, the weak sustainability assumption that presumes capital is fungible. Even if this is reasonable in that it provides a measure of capital that will maintain a real consumption flow, it ignores sustainability issues at a disaggregated level. At worst, it assumes a substitutability that may not be appropriate. Further, Nordhaus' (1995) point that technical change is a vital component of sustainability carries with it its own tensions. On one hand, ignoring the prospect of beneficial technical change (as many studies do) leads to the risk of adopting excessively conservative (and costly) policies to achieve sustainability, while in contrast, there is a danger of achieving 'sustainability by assumption' in

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presuming that technology will continue to generate productivity gains and environmental improvements simultaneously.

Other controversies, some indicating tension between accounting-based approaches and economic approaches, have been highlighted. A key one is whether or not to allow consumer surplus to be included in the aggregate measures being constructed. A strict accounting approach would not include consumer surplus, because such surplus is not a part of national income, and its inclusion would violate the rules of accounting consistency. On the other hand, many of the environmental benefits that economists try to measure typically include consumer surplus (and arguably should do). But to include such elements in an aggregate income-type index makes interpretation difficult (we note that the original Weitzman model avoided issues of consumer surplus by assuming utility linear in consumption).

Our scepticism regarding the ambitious agenda of some economists to provide a compelling rationale for NRA, and to derive detailed formulae to generate the appropriate index, leads us to a very guarded endorsement of the more cautious approach taken with respect to the SEEA. The development of the SEEA certainly provides an impetus for national statistical authorities in the area of data collection with respect to environmental and resource issues. The questions that remain are to do with the nature and intended purpose of any data collection exercise intended to facilitate the construction of a satellite account. There is a danger that data will be collected, and satellite accounts constructed, without a clear policy or resource management purpose in mind. That is, we might collect data on the basis that we can imagine an accounting framework it can be fitted into, rather than a well-formulated question it might help us answer.

Economists, currently, are actively researching into extensions of growth-theory models to solve particular technical problems. They are also participating in case studies modifying aggregate economic 'performance measures' for various countries or regions. We doubt that these efforts will yield general and robust measures or methods, and question the worth of much of this work. However, economists are spending comparatively little time examining the SEEA proposals and coming to terms with the strengths and weaknesses of these. Yet these are the foundations for future official accounting revisions and practices in the environmental and resource area. It may be that professional resources in this field ought to be reallocated.

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Appendix A

Table 1 Economic applications

Authors	Year	Country	Study period	Coverage	Method	Results
Adger & Grohs	1994	Zimbabwe	1987	Forestry & soils	Modified NNP – change in productivity and replacement cost techniques	Forestry – ZM$94million Soil – ZM$5.65 million
Adger & Whitby	1991	UK	1988	Agriculture & forestry	Peskin (1989) net environmental benefit	Net benefit £856 million
Adger & Whitby	1993	UK	1988	land-use sector	Daly (1989) modified net welfare	£888 million non-market services plus £63 million net investment
Bartelmus	1994	PNG	1986–1990	Fisheries, forestry & minerals	NP	NDP lowered by between 1% and 8% over time period
Bartelmus	1999	Philippines	1988–1994	Fisheries, forestry, minerals, emissions & waste sinks	NP and maintenance cost	EDP exhibits a non-decreasing trend
Common & Sanyal	1998	Australia	1988–1992	Minerals	NP and UC	Approaches yield significantly different estimates
Crowards	1996	Zimbabwe	1980–1989	Forest, minerals & soils	NP and UC	Depreciation equivalent to 2% of annual GDP
Foy	1991	Louisiana	1963–1986	Revised State GDP (GSP)	NP and UC	NP GSP 3.3% lower, UC GSP 13.8% lower – significant proportion Louisiana income from consumption natural capital

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Table 1 Continued

Authors	Year	Country	Study period	Coverage	Method	Results
Golan, Adelman & Vogel	1999	California	1982	California cotton water externality	Environmental NNP derived from current environmentally adjusted Social Accounting Matrix (SAM)	Effect externalities on economic activity – overstate true gross economic activity $8.9 million in unadjusted SAM
Grambsch, Michaels & Peskin	1993	USA	1982 & 1985	Environmental services – market and non-market	Peskin (1989) – ENRAP	Net nature sector output 1982 US$1188 million and 1985 US$1218.5 million
Hanley, Moffat, Faichney, Wilson	1999	Scotland	1980–1993	Macro economy	Green NNP	Environmental depreciation 6 billion pounds sterling 1993
Hrubovcak, LeBlanc & Eakin	1999	USA	1982, 1987, 1992	Agriculture	Resource adjusted NNP – soil productivity, water quality and groundwater quality	Only minor adjustments to NNP – biggest impact from surface-water quality decline
Hultkrantz	1992	Sweden	1987	Forest Products	Modified NNP	5.5 billions SEK additional contribution to GNP
Liu	1996	China	1976–1992	Coal	NP and UC	NP results erratic and unreliable. UC net investment negative.
Liu	1998	China	1976–1992	Forestry	NP and UC	Significant difference between results NP and UC
Neumayer	2000b	103 Countries	1970–1994	Oil, gas, copper, bauxite, forestry, gold, iron-ore, tin	NP and UC	Assessing sustainable resource use. Policy results are ambiguous depending on choice of method

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Table 1 Continued

Authors	Year	Country	Study period	Coverage	Method	Results
Repetto	1993	Costa Rica	1970–1989	Fisheries, forests and soils	NP	Accumulated depreciation 1984 prices US $4.1 billion 5% GDP p/a
Repetto, Magrath, Wells, Beer & Rossini	1989	Indonesia	1971–1984	Timber, petroleum and soil	NP	Annual GDP growth from 7.1% to 4% p/a
Tai, Noh & Nik	2000	Malaysia	1982–1993	Fisheries	Present value of future rents	Optimal value fisheries increased if current fishing effort reduced
Van Tongeren, Schweinfest, Lutz, Luna & Martin	1993	Mexico	1985	Forestry, oil and land use	NP	2% disinvestment
Vincent, Panayotou & Hartwick	1997	Indonesia	1971–1984	Petroleum (Repetto *et al.* 1989 data)	Net investment (Hotelling rent & capital gains)	Inclusion of capital gains substantial impact on estimated level investment required
Vincent	1997	Malaysia	1970–1990	Mineral, oil & timber	Per capita green net investment and green NDP	Per capita net investment positive all years but one; per capita green NDP grew
Vincent & Castaneda	1997	14 Asian countries	1970–1992	Minerals, timber and agricultural soils	Total and Hotelling rents for minerals and timber; productivity change for agricultural soils	Need savings to offset resource depletion more critical in future. Soil degradation most important cause depreciation in early 1990s

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Table 1 Continued

Authors	Year	Country	Study period	Coverage	Method	Results
Winter-Nelson	1995	18 African countries	1970s and 1980s	Minerals	NP and UC	Reduction GDP greatest for countries with large extractive industries
Young	1993	Australia	1980–1989	Erosion, salinity, habitat decline and minerals	NP and maintenance cost	Minimal net effect
Young & da Motta	1995	Brazil	1970–1988	Minerals	NP and UC	Large oscillations with NP due to influence of changing estimates of reserves. UC results more stable

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