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# SOME UNPLEASANT NATURAL RESOURCE ACCOUNTING ARITHMETIC: NOTES TOWARDS AN IMPOSSIBILITY THEOREM

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**PRELIMINARY—PLEASE DO NOT QUOTE**

## Abstract

Natural resource accounting has been the subject of much recent attention, both from economic theorists, and from government agencies seeking to redefine the way national income is measured in practice. The implicit objective seems to be one of generating a more accurate measure of true changes in economic well being resulting from production and resource-use decisions. Formally speaking, we would like to link a backward-looking measure of income (consumption plus change in wealth) and a forward-looking measure of income (sustainable consumption). In this paper, I analyse a simple example of a resource-dependent economy, and conclude that it seems in general no index number of "environmentally adjusted" national income will fulfil such an objective. Regardless of how well environmental adjustment of national income is carried out, the welfare and sustainability implications of economic growth are ambiguous.

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## 1. Introduction

Natural Resource Accounting (henceforth NRA) refers to the proposed amendment of national accounts aggregates so as to more accurately reflect annual changes in the stock (or quality) of "natural capital". In other words, while we currently measure production of goods and services in our gross income measures, we ignore the changes in air, water and soil quality, the deforestation, the depletion of oil and fish stocks etc. which reflect what we have used up of our "natural endowments" in order to generate those goods and services.

Those who endorse undertaking environmental adjustment of national income figures claim --quite reasonably---that the present national income figures are seriously distorted; by adding up what we *produce* in a period without taking into account what we have *consumed* of nature's endowments, the accounting system encourages (or, more precisely, does not penalize) overexploitation of the resource base, relative to an efficient benchmark. The implicit presumption seems to be that such adjustment will "re-balance the scales", and in doing so, provide useful information regarding our rate of resource exploitation, thus providing an incentive to utilize natural resources more efficiently. A metaphor that has appeared in the literature is that we are "steering by the wrong compass" when we make policy decisions based on current (unadjusted) national income figures.[1]

Numerous questions arise from the foregoing discussion. Some pertinent ones include the following.

i) How should the adjustments be performed, both in principle, and in practice given data limitations?
ii) Where should any given adjustment be performed (stock accounts, flow accounts or both)?
iii) What is the nature of the policy formulation process by which a change in national accounting methodology might lead to more efficient use of natural resources?
iv) What signals regarding our resource use are actually provided by "greening" the national accounts?

The first two, more practical, questions have received extensive treatment by authors such as Robert Repetto of the World Resources Institute (Repetto 1988, 1989), Salah El Serafy of the World Bank (El Serafy 1989), Jonathan Levin of the International

[1] Particularly when those policy decisions have implications for the natural resource base.

Monetary Fund (Levin 1991) and the OECD (1994). In fact, the United Nations, overseers of the present standardized System of National Accounts (SNA), have outlined a satellite system of environmental accounts, the System for Integrated Environmental and Economic Accounting (UN 1993). The Australian Bureau of Statistics is currently developing a program of evaluation of possible additions to its measurement of income in the light of these developments elsewhere.

By contrast, the last two, more conceptual, questions have been relatively neglected. The nature of the public policy process, and the role of national income statistics in that process, has been mostly ignored in the literature, a neglect which is unfortunate given the implicit presumption of NRA advocates that changing our accounting methodology is a prerequisite for improving our resource use. This situation is changing; informal discussions of the role of national accounts in the policy process are contained in Brekke (1994), Harris (1994) and Aaheim and Nyborg (1995).

The final question has been given more attention recently, following the seminal work by Weitzman (1976); however, this discussion has been confined mostly to competitive optimizing economies, which turns out to be a severe limitation. Harris (1994) and Aaheim and Nyborg (1995) note that this optimality assumption renders the role of natural resource accounting moot; the point, presumably, of undertaking such adjustment is that current practices are anything but optimal (efficient) and that employing NRA is part of the process of improving our resource use. Both of these latter papers present some discussion of the more general issues involved in interpreting "greened" national income statistics.

Aaheim and Nyborg (1995) frame their discussion in the context of the logistical and data difficulties inherent in generating plausible national-level statistics on resource use. By contrast, the discussion below will assume all such difficulties away. I plan to demonstrate that even when all physical quantities and shadow prices are known with complete accuracy, adjusted national income provides us with no coherent information regarding either efficiency or sustainability of resource use.

## 2. What Would We Like National Income To Tell Us?

National income, as currently measured, is most defensible simply as an indicator of current market level activity. Conventional Gross Domestic Product explicitly excludes productive activity outside the market sector, just as it excludes activity which degrades

environmental capital, broadly defined. This is exactly the bias which, it is argued, needs to be rectified by—in particular—environmental adjustment of national income.

If we could remove this bias, what would we like to end up with? Two related possibilities for an "ideal" income measure to possess are suggested here.

The first criterion that an ideal measure of income would satisfy is a *decision rule* one: income would provide us with a guide to the efficiency or otherwise of our natural resource use, enabling us to make better decisions. This stems from the idea that with our current national accounting system, we are "steering by the wrong compass". Appropriate amendments would, arguably, correct the compass so that we are accounting for the relevant social costs of resource use and environmental degradation; and this corrected compass would improve our ability to make efficient resource-use decisions.

Another criterion we would like an income measure to satisfy is a *measurement* one: that we could measure growth over a period of time and draw a conclusion about whether such growth was "sustainable" or not; or at least that such measured growth was a truer measure of the change in living standards in the economy than is provided by our current measures. The fact that economists from James Tobin and William Nordhaus to Robert Repetto have undertaken adjustments to conventionally measured income in a number of different countries, suggests that they take seriously the notion that a time series of adjusted national income provides a truer picture of real economic growth than a time series of the conventionally measured figures.

We can formalise this discussion by noting the two conventional definitions of income used by economists (see Bradford 1990). One is what Bradford refers to as the Schanz-Haig-Simons (SHS) definition of income as consumption plus the change in the value of wealth within a period. Bradford notes that this is *backward-looking* in the sense that it focuses on the economy's recent history. The second definition is the Hicksian one, of income as that amount which could be consumed per period in perpetuity. This is *forward-looking* in that it is a measure of the economy's (potential) productive capacity.

Perhaps the goal of advocates of NRA, as represented in the following quote by Rymes (1993):

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

is best summarised as that of obtaining forward-looking information from backward-looking measures of income

There exists a formal literature which does seek to investigate the linkage between the SHS and Hicksian conceptions of income, stemming from Weitzman (1976), although his paper was in part preceded by Samuelson (1961). As summarized in Dasgupta (1990, p60), it is *definitionally* true that real net domestic product (NDP) is the sum of the social value of an economy's consumption plus the social value of the changes in its stocks of real capital assets. With accurate accounting (shadow) prices, an optimizing competitive economy will choose the flow of its consumptions and net investments so as to maximize real NDP at each date. What Weitzman demonstrated was that real NDP[2] at any date along an optimal consumption path reflected that economy's long run consumption possibilities—that is, NDP indicates the level of consumption which, 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.

In viewing Weitzman's result as a reconciliation of SHS and Hicks, caution needs to be exercised. Aaheim and Nyborg (1995) point out that Weitzman's result does not reveal a *feasible* consumption level that can be maintained in perpetuity; what it shows is the *hypothetical* constant consumption path which has equivalent present-value-of-welfare implications to the *actual* consumption/investment path the economy is following. Weitzman mentions but does not investigate (depreciation of) types of capital such as exhaustible natural resources. When natural resources are incorporated into real NDP appropriately, "an ideal index would deduct depreciation of the country's resource stocks as well—valued, of course, at accounting prices." (Dasgupta 1990, p61.)

These extensions have since been formally performed by authors such as Hartwick (1990, 1994), Maler (1991) and Dasgupta (1995). The notable thing about pretty much all of this work is that it is focused on the meaning of NDP when (a) it is "appropriately" measured, and (b) it represents the solution to a dynamic optimizing problem. We have remarked above that NDP is thus being derived as a welfare measure, but one without any immediate *policy* significance! Presumably, the reason we want to be going to the trouble of computing the depreciation of our natural resource

[2] Weitzman and others tend to use the label "net national product", but for the purposes of our discussion there is no distinction.

base is to give us (or some policy makers who are charged with, say, resource management) some kind of signal regarding the wisdom of our current policy settings. Yet the Weitzman/Hartwick analyses are predicated on the assumption that all our policy settings[3] are as wise as they can be, in that they are a solution to the relevant social welfare problem.

Even notwithstanding this limitation, several authors have questioned the meaning of the Hamiltonian-as-income analyses described above. For specific criticisms, see Asheim (1994), Brekke (1994), Usher (1994) and Pezzey (1995). Meanwhile, the first explicit attempt I am aware of to analyze what the appropriate welfare measure would look like *away* from the optimum is by Maler (1995). What he shows is that the appropriate measure in these circumstances is non-linear, containing changes in surpluses which are not part of conventional national income measures.

This then invites the question I am interested in; namely, how do we interpret the *linear* measure which is actually provided by the National Accountant? More specifically, what signals regarding resource use will we receive by using the suggested accounting procedures to adjust gross income to net income in order to reflect depreciation of the natural resource base, *given the possibility of inefficient resource depletion?* What I hope to demonstrate is that the signals are far less straightforward to interpret than might be assumed at first blush, and would need to be interpreted with extreme caution and insight in order to improve matters.

## 3. Net Income for An Optimising Resource-Dependent Economy

Footnoted to his observation above regarding the "ideal index", Dasgupta observes that employing such an index "leads to the seemingly paradoxical result that NDP in a country which lives solely off its exhaustible resources is nil, and it is nil no matter how high the current consumption is." Why this is so will be explained below when we revise the Hotelling principle and apply it to a simple example of a resource-dependent economy. We shall also establish that Dasgupta's comment is true only in particular circumstances; namely, when the rate of depletion is Hotelling-efficient, *or* when the current market price is presumed to be the shadow price—that is, if the depletion path is *assumed* to be efficient.

[3] That is, if there *are* any policy settings. One way of viewing these results is as a competitive laissez-faire equilibrium, where there aren't any policies to worry about.

The principal contribution of this paper is to show that not only can NDP in a resource-dependent economy be non-zero, but that that fact has some important and neglected policy implications.

The approach I shall take is to analyze various national accounting methodologies and related resource-use "decision rules" in a simple example of a resource-dependent economy. By decision rules, I mean national income-related criteria which might be used as guidelines in making resource-use decisions. These rules will be spelt out explicitly below.

The simple set of examples described below (and in the Appendix) will involve what I will label a "guano economy"—one that lives solely and directly off the proceeds of extracting a non-renewable resource. The assumptions are as follows:

- the demand curve for the resource is given, time-invariant and known to all;
- the resource stock is given and known—no new stocks are found, at least not in any time frame which should concern us;
- there are no extraction costs;
- the proceeds of extraction are consumed—there is no reinvestment (physical or financial);
- there is no international trade;
- there are no stock effects (only currently extracted units of the resource contribute to current utility);
- there is no disutility associated with extraction or consumption of the resource (i.e. no pollution); and
- the analysis is conducted in discrete time.

The notation for the examples in the rest of the paper will observe the following pattern.

$Q_t$ = the total (remaining) stock of the resource at the beginning of period t.
$q_t$ = the amount extracted in period t.
$p_t$ = the unit market price in period t, given extraction $q_t$.
$\boldsymbol{p}_t$ = the underlying *present value* (i.e. evaluated at period zero) shadow price of the resource in period t, given extant stock $Q_t$.

These assumptions enable us to portray the impact of resource extraction on unadjusted national income as follows. Some amount of the resource will be extracted in period zero, and sold at the market price associated with that quantity. This will be measured as that period's Gross Domestic Product, as follows:

(1) $GDP_0 = p_0 \cdot q_0$

From here, we need a method for adjusting the accounts. In reality, we will be limited by a great degree of ignorance regarding true changes in stock levels, the appropriate shadow prices and so on, and many of the discussions of NRA are written in the context of overcoming such data problems. The purpose of our example, however, is to allow ourselves to assume away any data difficulties and focus on national income as if we could compute it accurately with ease.

The most common approach for incorporating non-renewable resource depletion into the national accounts is the *depreciation* approach, as discussed by Repetto (1988), Repetto et al. (1989) and Dasgupta (1990) among others. The logic of this approach is equivalent to the treatment of produced capital in the computation of Net Domestic Product (NDP) – as well as *adding* the value of newly produced capital as part of gross income, one would wish to *subtract* appropriately measured depreciation of the existing capital stock.

The question then becomes one of appropriate definition and measurement of depreciation. The literature provides more than one way to skin this particular cat, although Dasgupta's stricture above provides a stern hint about the most appropriate "textbook" approach to defining depreciation. With that in mind, we restrict our focus in this section to what we might label an "orthodox" measure, then in the subsequent section discuss some alternatives which may be of interest.

Being mindful of Dasgupta's comment about valuing changes in stocks at accounting prices, and Maler's (1991) dictum:

> "The value of the change in the stock (not the change in the value of the stock) should be included. Anticipated capital gains are not parts of national income." (p7, Maler 1991.)

it should be clear that the orthodox approach is to define per-period depreciation of a natural resource as shadow price times change in resource stock, i.e.

(2) $NDP_0 = GDP_0 - depreciation = p_0 q_0 - \boldsymbol{p_0} \cdot q_0$

To understand how we should think about depreciation (and the $p$s, shadow values) in this context, it is useful to go back over what we know about the theory of natural resource depletion, in particular the "optimal depletion" arguments developed by Hotelling (1931). Hotelling's solution characterized a competitive equilibrium in

resource markets, but the important point is that—like many nicely behaved competitive equilibria—it can be derived from the solution to an optimizing (welfare maximizing) problem. It should be stated upfront that the optimizing problem takes the specific form of a present-value-of-utility maximizing problem, which thus has no *explicit* intergenerational focus.

The key feature of Hotelling's solution was that the resource price (net of extraction costs where these were positive) would rise over time at a rate equal to the interest rate, and exhaustion would occur just as the resource price hit the "choke price". The choke price is defined as either the price where demand for the resource falls to zero, or else where an alternative technology becomes economically viable.

Thus the depletion path defined by Hotelling has the property that the present value of a unit of the resource stays constant over time. The present value of the total stock will change by the value of the amount depleted. In other words, along the depletion path we have defined $p_0 = p_0 = p_t, \forall t \in (0,T)$, where T is the period in which exhaustion occurs, and so the depreciation term exactly cancels out the value of the current sales, leaving *Net* Domestic Product equal to zero.[4]

This is a well recognized result (see Dasgupta 1990; El Serafy 1989), even if Dasgupta describes it as "seemingly paradoxical". (For the purposes of the rest of this paper, the unit shadow value of the resource, $p_t$, will be derived from the Hotelling optimization problem.)

However, we are interested in more general possibilities than resources being depleted "optimally". Rather, we are interested in the question of how adjusted national income is affected by different rates of resource depletion. By examining this question, we can examine in turn whether and how the quality of the signals—the "direction of the compass"—is improved (or not) by measuring and deducting depreciation of the resource base from gross income. In other words, can we use the relative levels of NDP at and away from the optimum as a guide to where the optimum actually is?

## 4. Income in a Non-Optimising Economy

[4] Landefeld and Hines (1985) discuss several ways in which depreciation can be valued *in practice*. These will be evaluated briefly at the end of Section 3.

Here we will examine the changes in income which occur as the economy moves away from efficient resource depletion. In particular, do we see *falls* in adjusted income if we diverge from the efficient level?[5]

This is really a formalisation of the "compass" metaphor: If we take efficiency in depletion to be our aim, then an appropriate compass will guide us to efficiency by providing the maximum reward when it is obtained. This is summarised in the following definition.

**Definition:** *A national accounting methodology is said to be* ***welfare-consistent*** *if national income is maximized when the economy is at a Pareto optimum.*

The idea of welfare-consistency as defined above seems to be a reasonable property for a well aimed economic "compass" to possess (where the Pareto optimum in this context is defined as the level of extraction in a period consistent with the Hotelling efficiency condition, defined given the extant stock at the start of that period.). The current practice in national accounting, which ignores many economically valuable forms of production and consumption, is virtually by definition in violation of this criterion (see the discussion of GDP in this example below). In practice, welfare-consistency allows us to treat national income as an objective function or welfare criterion. Higher income is better. (See Figure 1.)

Given that we have established a benchmark level of zero NDP as consistent with efficiency in our example, the question becomes, is zero the *maximum* NDP achievable? That is, is it the case that inefficient extraction gives us *negative* NDP?

**Proposition 1:** *Gross domestic product, as defined in equation (1), is not welfare-consistent.*

**"Proof":** (Most of the proofs in the text will be heuristic; some more detail will be provided in the Appendix.) Given the static market conditions assumed in our example (where only the total stock changes through time as a result of extraction), the condition for maximizing GDP is the same in every period, implying a constant rate of depletion through time. Efficiency requires, on the other hand, declining extraction per period

[5] One point of clarification needs to be made at this stage concerning the derivation and interpretation of the shadow price $p_t$. In a discrete-time analysis, it could refer either to a beginning- or an end-of-period value. In the latter case, extraction in period t affects the shadow price in that period, while in the former case the shadow price in period t remains unchanged while that in period t+1 changes as a consequence. We will typically assume that it is beginning-of-period measure unless stated otherwise.

and consequently a rising price path. Thus maximizing GDP can not be compatible with efficient extraction.

**Proposition 2:** *Net domestic product as defined in equation (2) is not welfare-consistent.*

**Proof:** In equation (2), for national income to be welfare-consistent requires, as described above, that NDP be non-positive when resource use is inefficient since it is zero when resource use is efficient. In the context of our example, we rewrite equation (2) as follows:

(2') $NDP_0 = (p_0 - p_0).q_0.$

It can easily be seen that for any $p_0 > p_0$, NDP will be non-negative, only reaching zero when $p_0$ hits the choke price (i.e. when $q_0 = 0$). If it can ever be the case that the actual price in any period is greater than the shadow price associated with the resource in that period, then NRA-adjustment does not lead to welfare-consistency of national income.

To demonstrate that NDP is not welfare-consistent (that is, it is possible that $p_0 > p_0$) is trivially easy. For beginning-of-period shadow prices, they are *defined* as constant through that period. So any quantity extracted below the $q_0$ consistent with given shadow price $p_0$ would drive the market price above the shadow price and raise NDP above zero. For any downward sloping demand curve defined over all $q$, this is possible for any shadow price below the choke price.

By contrast, end-of-period shadow prices are influenced by current extraction. Any extraction levels compatible with positive NDP as described above will be conservative with respect to the efficient level of extraction. The remaining stock will be larger than it would have been had the efficient amount been extracted, thus driving the current shadow price down, resulting in NDP being not only positive but greater than it would be if we were using beginning-period shadow prices. QED.

**Lemma:** *Maximizing NDP results in a conservative depletion path being followed relative to the efficient path.*

The intuition for this result should be obvious from the discussion above; and all of the points established above can be illustrated easily on a simple diagram. (See Figure 2.)

For a given shadow price, a higher price results in positive NDP. The sum of the shaded areas represents GDP, the dark area is depreciation and the lighter area is the difference i.e. NDP. It is easy to see that inflating national income involves reducing extraction in any period below the efficient amount which would bring the shadow and market prices into line. If we take the objective function which generated the shadow prices as the appropriate one, and if there are no externalities unaccounted for in the arithmetic when we have done (which might warrant slower depletion than economic efficiency would dictate), then this is not an encouraging result.

## 4. Some Brief Extensions

So much for the orthodox approach to depreciation. Other techniques for imputing depreciation to depleted resource stocks can be found in the literature. One can be gleaned from Hicks himself:

> "Let us then define the depreciation of the original stock of capital as the difference between the total value of the goods comprising the original stock as it is at the end of the year ($C_1$) and the value ($C_0^*$) *which would have been put upon the initial stock at the beginning of the year if the events of the year had been correctly foreseen, including among those events the capital value* $C_1$ *at the end of the year.*' (p 136, Hicks 1942, emphasis in original.)

It would seem that the most appropriate—or perhaps just the most obvious—way to interpret Hicks' version (which he describes as the "Swedish" definition of depreciation) in the context of my simplistic story is to apply the period t+1 shadow price to the period t capital stock. In my notation, $C_1 = p_1 Q_1$ and $C_0^* = p_1 Q_0$, giving us:

$$NDP = p_0 q_0 - (p_1 . Q_0 - p_1 . Q_1)$$

(3)

$$= (p_0 - p_1) . q_0$$

This can be shown to violate welfare-consistency as easily as was shown for the orthodox measure of income in the previous section.

In a search for a welfare-consistent income measure, we may be tempted to violate Dasgupta's and Maler's injunctions, and measure depreciation as the full *change in value* of the stock, rather than just the physical change evaluated at a fixed shadow price. This implies an income formula as follows:

$$(4) \qquad NDP_0 = p_0 q_0 - \left[p_0 \cdot Q_0 - p_1 \cdot Q_1\right]$$

We can rewrite the above expression as:

$$NDP_0 = p_0 q_0 - \left[(p_0 - p_1) Q_0 + p_1 \cdot q_0\right]$$

$$(4') \qquad = (p_0 - p_1) q_0 - (p_0 - p_1) Q_0$$

This is a more complex expression than the others we have encountered thus far. Changes in extraction in a period will now have more mutually offsetting effects on income than before. Will these effects be sufficient to provide us with a welfare consistent measure? Some discussion as to why the answer is No is provided in the Appendix.

For completeness, we should note that the nominal/real dichotomy becomes complex in the Weitzman/Hartwick et al. world. While the Hamiltonian analyses of these authors have been conducted in terms of current price NDP, it is *real* NDP in the sense that it is a reflection of real (present value) consumption possibilities, at least if the Hotelling path is being followed. The resource price rises over time, but that is directly due to the continuing depletion of the resource, it is not inflationary in the typical sense, but rather reflects real changes in the shadow price. The Weitzman/Hartwick result thus concerns real NDP, but it is computed using each period's prices.[6] Brekke (1994) has pointed out that the standard accounting approach to calculating real NDP involves using *constant prices across periods*, which will produce different figures to those produced by using the Hamiltonian approach.

Out of curiosity, what would real NDP look like in this context if calculated with a base year price? The shadow price as used in the depreciation term should still be that which prevails in the period being analyzed, but the market price used to value the amount extracted will be kept in base year terms, so that NDP in period 1 (say) will look like:

$$(5) \qquad NDP_1 = \left[p_0 - p_1(1+r)\right] q_1$$

... would obviously be negative along the Hotelling-efficient path since $p_0 = p_1 < p_1(1+r)$. But, again, judicious extraction could ensure that this was positive if desired. Thus, this measure also fails the welfare-consistency test.

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[6] And along the Hotelling path, market and shadow prices are identical.

The applied literature on NRA has put forward practical proposals for adjusting national accounting measures for resource depletion, and these can be discussed at this point in the light of the above results. Landefeld and Hines (1985) discuss two key methods of adjustment. One is the Present Value method, in which, as the name suggests, an explicit attempt is made to estimate the discounted net value of future sales of the resource. An easier method is the Net Price method which just imputes the current net price to units left in the ground; this implicitly assumes that a competitive equilibrium is prevailing. Obviously, if such an equilibrium does prevail, both methods yield the same result. However, that neither of these pass the test of welfare-consistency is shown in the Appendix.

In Harris (1994), I also discuss the User-Cost adjustment advocated by Salah El Serafy (see El Serafy 1989) as an alternative to the depreciation approach, which he argues is inherently flawed. In the Appendix I summarise my arguments from that earlier paper as to why El Serafy's adjustment also fails to satisfy welfare-consistency.

## 5. Decision Rules

NRA-adjustment of national income accounts is proposed in order to produce figures which more accurately reflect true economic welfare, and/or sustainable national income[7] (or even "sustainable growth"). Doing this is presumably important because, as mentioned above, measures of economic activity/growth play a key role as inputs into policy decisions.[8] If they did not, it would be a safe presumption that there would be less support for, and impetus towards, implementing some form of NRA.

What this means is that we need a way to interpret the index numbers generated using NRA, in such a way as to promote efficiency in resource use. That is, are there any *decision rules* based on the NDP measure generated in equation (2) which help achieve that end?

The idea of a decision rule, as I employ it, is similar to that of a conventional objective function in economic analysis; that is, something to be maximized or minimized. My

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[7] It should not be assumed that these concepts will be quantitatively equivalent.

[8] I have already noted that this raises a number of so-far unanswered questions about the role of the national accounts as an influence on policy, and the subsequent impact on resource use decisions. These will be to do with who actually owns the resource (e.g. public or private sector, or both) and what policy role the public sector takes with respect to the resource industry. Some of these issues are discussed more fully in Harris (1994).

choice of terminology is simply to highlight the policy decision-making process I am interested in considering. That is, given different possible quantities of the resource which could be extracted within a period, and the NDP figure associated with each of those quantities, what decision rule results in what choice of amount to be extracted in that period?

The first and most obvious such decision rule, choosing the quantity which maximizes income (NDP) per period, does not serve to promote efficiency, as was demonstrated above in the discussion on welfare-consistency.

What of economic (NDP) *growth*? How are we to interpret year-by-year changes in national income, having adjusted national income in the ways theory suggests, and how might these changes be used as a decision criterion? Here our guano economy example is instructive. We know that, if we are using our non-renewable resource efficiently, growth ought to be zero since efficient depletion is zero every period. However, it should be clear that since it is possible to produce a positive NDP in each period, it is possible to produce positive *rates of growth* in NDP if they are desired. But since a positive figure for either net income, or growth in net income, is economically inefficient—even if one or other seems to be a politically sensible thing to aim for, not least because it *looks* economically responsible—neither maximum NDP nor maximum growth in NDP over some horizon can be taken as useful efficiency indicators.[9]

What about moving beyond the aggregate index number labeled NDP, and using its components as a guide to resource use? In more complex models, we could disaggregate at a number of levels, but in our simple guano economy the most obvious and relevant disaggregation is between the two components, gross income and depreciation. Depreciation as a proportion of national income hardly seems like a sensible basis for a decision rule, in the sense that there is no obvious justification for treating it as something to be maximized or minimized (given that it could be negative). Once again, from the Hotelling condition, it is clear that depreciation, correctly measured, should be just equal to gross income from extraction. (While this is appropriate given our best estimates of the shadow price of the resource, keep in mind that this holds by construction if we use the Net Price method of evaluating depreciation as described in Section 4 above.)

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[9] This is not necessarily confined to non-optimizing economies. Brekke (1994) discusses an example of optimal policy choice in which maximizing NRA-adjusted income growth conflicts with adjusting welfare.

It might be fairly concluded that the most useful information content deriving from NRA adjustment of national income comes from the disaggregated components of national income, rather than the index number itself. While the index number does in fact admit of an economic interpretation, to be discussed in the next section, there is a case for claiming that the parts are more illuminating than the whole.[10]

## 6. Interpretation and Discussion

As I have already intimated, the results so far give rise to questions and concerns regarding the public policy aspects of natural resource use, and what role environmental adjustment of national income might play in the policy process. Specifically, some seemingly reasonable resource use rules of thumb based on appropriately adjusted national income fail basic conditions of economic efficiency in resource use. So what do adjusted measures of income actually tell us?

An examination of Figure 1 can help provide an interpretation of the "orthodox" measure of income. For each unit extracted, there is a net (marginal) addition of welfare to the economy, given by the price as read off the demand curve less the shadow price. At whatever final quantity is extracted in a given period, the marginal contribution to welfare is then multiplied over the units extracted.

This provides another interpretation of the observation that NDP is zero over the efficient path. The standard marginal reasoning should make clear that one should extract in every period until the marginal contribution to social welfare is zero. However, at quantities below the efficient level, the marginal contribution is positive. The problem I have outlined above arises because we conventionally give this magnitude (NDP) a *total* interpretation, implying bigger is better. For marginal measures, less is typically more, certainly it is true here until we get to zero.

Of course, for those who think that when it comes to natural resources, slower is always better, this probably gives them more reason than ever before to advocate NRA adjustments to national income. Conservative depletion can (misleadingly) raise nominal national wealth and income. The economy-environment trade-off never looked so good.

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[10] Robert Solow (in Solow 1991) suggests that simply keeping tabs on how much of (gross) national income comes from non-renewable resources is useful if we believe that reinvesting resource rents is a useful rule of thumb for sustainability.

What it appears we cannot do, however hard we try, is to devise a form of income adjustment along the lines suggested by the theory and the literature, which satisfies welfare consistency (i.e. readjusts the compass to point "true North"). Nor does it seem we can take time series figures of adjusted income and draw convincing conclusions about anything to do with the "sustainability" of growth or the real growth in standard of living or productive capacity.

## 7. Concluding Comments

The above results show that a single index number constructed using appropriate accounting procedures and accurate shadow prices provides neither a measure of social welfare or of sustainable income in the context of an economy with natural capital. This raises important questions regarding what the adjustment of our national accounting procedures is intended—or expected—to accomplish. This is not to deny that there may be a case for undertaking NRA-adjustment; there seems to be a view in some quarters that existing national accounts practices are sufficiently incomplete that anything that could be done to improve them would be of benefit.

On the face of it, this is not an unreasonable view. Better numbers are better than worse numbers. But they may just be better bad numbers. The key questions are, what are they meant to help us achieve—and how? And are there better areas in which to direct our efforts to achieve those ends?

I would summarize the moral of the story as follows.

1. There needs to be an explicit discussion about what role national income figures are expected to play as policy inputs before we even talk about what numbers are better or worse, or how to make them better or worse.

2. Instead of improving measures of a single number, economists should—at least as an advice-giving profession—start advocating the idea that single number measures may be so inherently misleading that sensible policy recommendations should be based on the relevant disaggregated numbers rather than aggregates of dubious valuable.

In relation to point (2), I think for any given natural resource it is fair to say (and nothing I have argued contradicts this) that what matters when we are worried about sustainability and/or welfare is the physical stock of the resource, and (our best estimate

of) its shadow price. What I *have* argued is that sticking that information into a larger index number and calling it NDP is—in and of itself—not a solution, either in practice or conceptually, to any apparent policy problem that I can think of.

One argument for undertaking the NRA process is that the effort of gathering data on stocks, and attempting to value them is, to the extent we can do it sensibly, information it will generally be worth knowing. (To the extent that we *know* we cannot do it sensibly, we will be confronted with yet another "measure of our ignorance", and it is also probably a useful thing to know what we don't know, as long as we are honest about it.) But, to restate the point, it is the disaggregated data, not the aggregate index it is fed into, that is worth paying attention to.

In his critical overview of this area, Common (1990) concludes his discussion with the following comments, which I feel is sufficiently compatible with the arguments above that I can use it to conclude here:

> "[T]he view appears to be that the next step of aggregation should be within the Extended Market Valuation approach. I disagree. I think that the next step should be work on the construction of models for policy analysis which use the physical data becoming available. A variety of modeling approaches would be worth following. An optimization driven approach would have the potential to generate shadow prices for aggregation and accounting, and to permit of the analysis of policy trade-offs. It might then be possible to begin to identify true relative scarcities. I do not, however, wish to argue for following a single approach to the exclusion of others. The problems involved are complex and serious and policy development will no doubt benefit from a variety of methodologies being brought to bear on them."

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# APPENDIX

## Violations of Welfare Consistency

*GDP is not welfare-consistent:*

$$\text{Max} \quad GDP_t \equiv p_t(q_t)\,q_t$$

$$\text{FOC:} \quad GDP_t' = p_t'\,q_t + p_t = 0$$

which solves for the quantity $q_t = -\dfrac{p_t}{p_t'}$. Given a negative, monotonic relationship between $p$ and $q$, and invariance of demand for the resource, then $q_t$ will be positive; and if (as assumed) there are no discoveries of new resource stocks then $q_t$ will be constant for all t. This is sufficient to violate Hotelling-efficiency which requires a rising market price, and declining extraction, over time. QED.

*NDP (orthodox depreciation) is not welfare-consistent.*

$$\text{Max} \quad NDP \equiv p_t(q_t)\,q_t - p_t\,q_t$$

$$\text{FOC:} \quad NDP_t' = p_t'\,q_t + p_t - p_t = 0$$

which solves for $q_t = \dfrac{p_t - p_t}{p_t'}$. (This is done for the case in which the shadow price is defined as at the beginning of the period, and thus is not affected by current period extraction.) With the same assumptions as above, it is the case that if $p_t < p_t$, then $q_t > 0$. For the shadow price to be less than the market price, the amount extracted must be less than the efficient amount. This violates the Hotelling condition that $p_t = p_t$.

For end-of-period shadow prices (that is, $p_t = p_t(q_t)$), quantity solves for $q_t = \dfrac{p_t - p_t}{p_t' - p_t'}$. Since $p_t' > 0$, it must again be the case that for $q_t > 0$, $p_t < p_t$ must hold, and the Hotelling rule is again violated. QED.

*NDP (Hicksian depreciation) is not welfare-consistent:*

This follows by an argument similar to the end-of-period shadow price above.

*NDP (full-change-in-value depreciation) is not welfare-consistent:*

A very sketchy demonstration of welfare-inconsistency is as follows. The first order condition in this case reduces to:

$$p_0 + p_0' q_0 = p_t - p_t' Q_t$$

which can be thought of as a "marginal revenue = marginal shadow cost" condition. By contrast, the FOC of the Hotelling problem simply equates shadow/actual prices in each period, in present value terms.

(A full worked example in which a specific contradiction of welfare-consistency is demonstrated for this version of income is available from the author upon request.)

*NDP (Net Price depreciation) is not welfare-consistent:*

It should be apparent that the Net Price method would result in NDP of definitionally zero, regardless of extraction. This method does not so much violate welfare-consistency as provide absolutely no useful information whatever.

*NDP (Present Value depreciation) is not welfare-consistent:*

To think about maximising income in this case, rewrite income by defining a value function for the resource stock, V(Q), which measures the present value of the stock extant at a given time, so that in period zero, as depletion is about to begin:

$$V(Q_0) = \sum_{t=0}^{n} \frac{p_t q_t}{(1+r)^t}$$

i.e. income is written as:

$$NDP_0 = p_0 q_0 + \Delta V(Q)$$

Welfare-consistency invites us to regard this expression as an objective function, such that the value function becomes:

$$v(Q_0) = \max_q V(Q_0) = \max_q \sum_{t=0}^{t} \frac{p_t q_t}{(1+r)^t}$$

Using Bellman's Principle of Optimality the FOC for this expression is:

$$p_0^i(q_0).q_0 + p_0 = -\beta v^i(Q_0 - q_0)$$

The interpretation of the first-order condition is that the social planner should deplete such that the marginal profit from extraction in a period is just equal to the change in present value of the remaining stock. This is because at the optimum, an increase in profit today will just be offset by an equal decline in the present value of the unexploited stock.

But what should be clear is that this problem is simply a decomposition of the more general one of choosing a depletion plan to maximise (3), and that is the objective function which would face a profit-maximising monopolist! In other words, the incentives provided to a resource manager who uses the impact of extraction on the national accounts as a guide to how to use the resource, suggest that the best thing to do is behave as a monopolist would, rather than as a competitive firm would.

*GDP (User Cost adjustment) is not welfare-consistent:*

In El Serafy's formulation, the relevant computation is:

$$GDP_t = p_t q_t - \text{user cost}$$

The user cost component is calculated by dividing receipts R into income X and user cost (R–X), such that if (R–X) was reinvested annually at the prevailing rate of interest, it would earn X in perpetuity. (See El Serafy 1989 for a detailed derivation.) Without performing any calculations, it is easy to establish that the same general incentives that

applied in the previous section also apply here. As El Serafy points out regarding his accounting methodology:

> "A country that liquidates its mineral reserves over fifty years needs to set aside for reinvestment a smaller portion of its receipts than another that liquidates its reserves over twenty years, and thus it can count a larger portion of its receipts as *income*." (El Serafy 1989, p14, emphasis in original.)

So, as before, slower depletion tends to be rewarded in the national accounts; here the reward occurs through slower depletion increasing the proportion of receipts being measured as income. Again there will be a trade-off since excessively slow depletion will reduce absolute receipts so much that having a higher proportion designated as income will no longer compensate. This point is unlikely to occur at levels of efficient depletion as characterised by Hotelling.

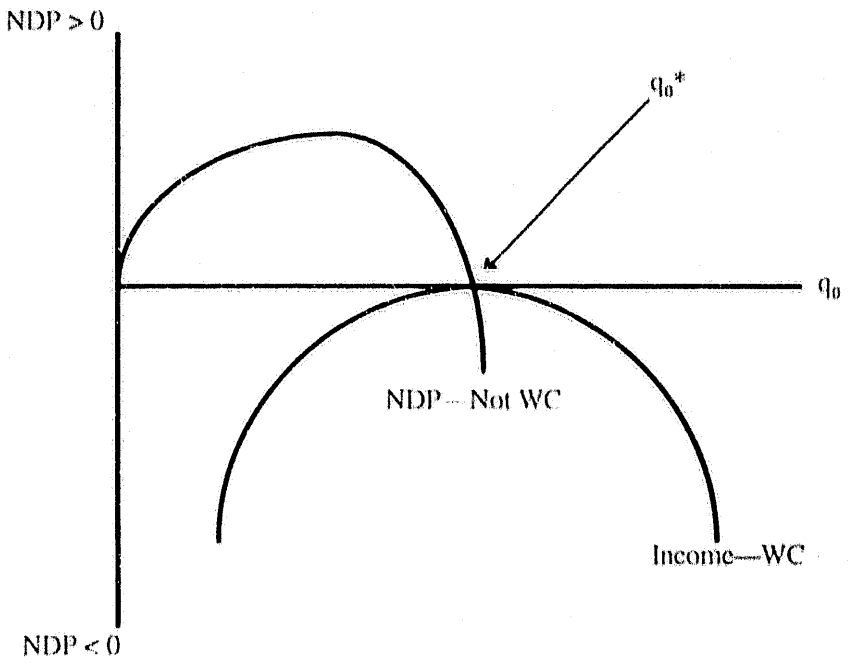


*FIGURE 1*

The orthodox measure of net income looks something like the higher of the two curves. A hypothetical welfare-consistent measure is shown in the lower one.

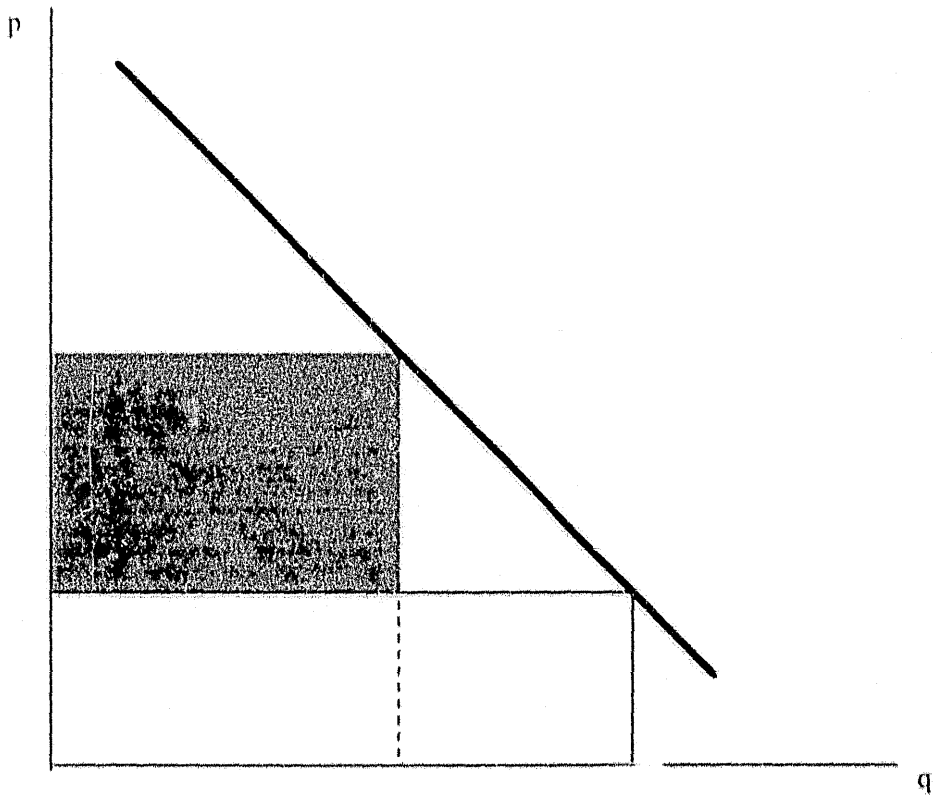


*FIGURE 2*

A simple diagrammatic demonstration of welfare inconsistency in a resource-dependent economy. The shaded area represents positive net income from inefficient (too little) extraction.