Accounting for Unexpected Capital Gains on Natural Assets in Net National Product

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Failure to separate unexpected capital gains and losses on natural assets from depletion breaks the link between Net National Product (NNP) and sustainability. In addition, for resource rich countries this can lead to large spurious fluctuations in NNP, making it virtually useless for policy purposes. In contrast, when depletion is measured correctly, the link between NNP and sustainability is restored and there is no reason to expect NNP to be any more volatile than GNP. Oil data for Great Britain and Indonesia are used to illustrate the very significant impact that the treatment of capital gains and depletion can have on NNP. (*JEL* O47, P44, Q32)

KEY WORDS: Capital Gains; Depletion; Income; Net National Product; Environmental Accounting; Sustainability

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1. Introduction

Interest in the measurement of depletion, capital gains and the sustainability of growth has been stimulated by the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, and the publication in 1993 of the new internationally agreed System of National Accounts (SNA).¹ The 1993 SNA has been criticized, however, by environmental groups for its failure to record the depletion of natural assets, such as mineral deposits or oil fields, in the production account and recognize it as a cost of production.² The values of the natural assets extracted form part of the values of the outputs of mining or oil companies, and hence are included in full in Gross National Product (GNP), but no charge is made for the using up of the assets which are not reproducible and not inexhaustible. Environmentalists, such as Repetto (1992), argue that the UN, World Bank and IMF are, therefore, indirectly encouraging countries to follow unsustainable paths of development because frequently the fastest way to increase real GNP in the short-run is to deplete the natural capital stock. Many developing countries seem to have followed such economic policies even though the growth rate of real GNP may be unsustainable in the longer run and provide a potentially highly misleading indicator of economic performance.

Net National Product (NNP) is defined in the SNA as GNP less the depreciation on produced assets, such as machinery and buildings (or consumption of fixed capital as it is called in the SNA). Although NNP provides a better indicator of economic performance it still fails to take account of the depletion of natural assets. Hence, Repetto (1992) and Pearce and Atkinson (1995) argue that NNP should be redefined by

¹The 1993 SNA was published jointly by the United Nations, World Bank, IMF, OECD and the European Community. It has been adopted by all the major countries in the world, including China, Russia and the USA, and provides the conceptual framework for all macroeconomic data used for analytic and policy purposes.

²Actually, depletion of natural capital is included in the 1993 SNA, but in the wrong place. It is recorded as an adjustment item to reconcile the values of stocks of natural assets in the opening and closing balance sheets but not in the production account.

deducting depletion as well as depreciation from GNP, a proposal that has the support of many national accountants also. The depreciation of produced assets and the depletion of natural assets have much in common conceptually and both need to be deducted when measuring the net value added created by production. In the rest of this paper we adopt this extended definition of NNP.³ As environmentalists argue, it provides a better indicator of economic performance and its adoption would encourage countries to follow more sustainable policies. Under certain conditions, NNP can be interpreted as the maximum level of consumption that would permit the overall capital stock (i.e., both produced and natural capital) to be maintained intact.⁴ Therefore, barring unexpected capital losses such as those due to natural disasters and assuming a nondecreasing real interest rate, a level of consumption equal to NNP could be maintained indefinitely.⁵ Hence NNP is much more closely linked than GNP to the concept of sustainability. A rise in a country's per capita real NNP should constitute sustainable development.⁶

In practice, both depreciation and depletion, and hence NNP, are difficult to measure, since they require estimates of changes in the values of capital assets. This largely explains the widespread use of GNP as an indicator of economic performance, despite its conceptual inadequacies. Frequently, insufficient data are available to estimate depreciation and depletion. Even when data are available, estimates of the depletion of natural assets are liable to be distorted by capital gains (losses).⁷

³This environmentally adjusted version of NNP is also sometimes referred to as ENP in the environmental accounting literature [see, for example, Bartelmus, Stahmer and van Tongeren (1993)].

⁴Strictly speaking this is only true if the relative price of consumption and investment goods is independent of the level of consumption, an assumption that is not that unreasonable for small open economies [see Weitzman (1976)].

⁵The impact of decreasing real interest rates on the maximum sustainable level of consumption and NNP is explored by Asheim (1997).

⁶This is not to say that a constant level of consumption over time is actually optimal. In general, unless society has maximin (or Rawlsian) preferences across generations, it will not be. The implications of maximin preferences for the use of nonrenewable resources is explored in Solow (1974).

⁷Partly for these reasons, depletion was excluded from the production account of the SNA. There was concern that its inclusion might undermine the integrity of the rest of the system, [see for example

The treatment of capital gains on natural assets in the national accounts has been discussed by, amongst others, Mäler (1991), Asheim (1996), and Vincent, Panayotou and Hartwick (1997). The general consensus that emerges from this literature is that all capital gains arising from discoveries of new stocks of natural assets or changes in the price of these stocks should be included in NNP. However, there is some controversy over the treatment of capital gains arising from changes in the interest rate. This controversy is discussed in the next section. More important in the context of this paper is the fact that, by assuming a perfect foresight setting, these authors completely ignore the treatment of unexpected capital gains.

This paper focuses on unexpected capital gains on natural assets and their implications for NNP.⁸ The main sources of unexpected capital gains on natural capital are changes in commodity prices and discoveries of new stock. Most empirical studies thus far [see for example Repetto et al. (1989) for Indonesia and Young (1993) for Australia] have included unexpected capital gains in NNP. As a result, the NNP series obtained by these authors are highly erratic. This is because the magnitude of the unexpected capital gains (losses) on natural capital can be huge for resource rich countries. A case in point is Norway. In some years, changes in the total value of Norway's stock of oil, due to price changes, have exceeded its GNP [see Aslaksen et al. (1990) and Aaheim and Nyborg (1995)]. By implication, in the mid-1980s when the price of oil collapsed, Norway's NNP would have gone negative if all capital gains (losses) on natural capital were included in NNP. Clearly, failure to separate unexpected capital gains from depletion may introduce spurious volatility into measured NNP, particularly for resource rich countries, thereby undermining its credibility as an indicator of economic performance.

El Serafy (1989) and Hartwick and Hageman (1993) address the problem of how to adjust NNP for discoveries of new stock. The methods proposed in these papers dampen

Thage (1991)]. Instead, separate "satellite" environmental accounts have been proposed [see Bartelmus, Stahmer and van Tongeren (1993)].

⁸In a related paper, Hill and Hill (2003) consider the implications for NNP of the treatment of other types of assets, as well as exploring more generally the link between income and capital gains.

somewhat the impact of discoveries on NNP, as does the method recommended here. Hartwick and Hageman also discuss briefly the treatment of unexpected price changes. Their position on this issue is consistent with our approach. Both the El Serafy (1989) and Hartwick and Hageman (1993) papers are discussed in greater detail later.

It is argued here that the correct treatment of capital gains in NNP hinges on the definition of depletion. Hotelling (1925) developed the economic theory underlying the concepts of depreciation and depletion. The concept of income, as discussed by Hicks (1946), is closely related. It is due to a persistent misinterpretation of both concepts that most empirical studies fail to separate unexpected capital gains from depletion so that measured depletion is often a confused mixture of the two. Lumping unexpected capital gains in with depletion has two disadvantages. First, it breaks the link between NNP and sustainability. The winner of a lottery (e.g., a country with large oil reserves when the price of oil rises) cannot expect to maintain a level of consumption equal to this lottery win period after period into the future. Second, it may cause measured NNP to become highly erratic. However, when the Hotelling concept of depletion is correctly implemented and unexpected capital gains are excluded (except for the interest earned on these gains), the link between NNP and sustainability is restored. Furthermore, it is shown that there is no reason to expect NNP to be any more volatile than GNP. Therefore, by treating unexpected capital gains correctly, the main obstacles to widespread use of NNP as a guide to government policy (i.e., the lack of a link to sustainability, and excessive volatility) are removed.

Illustrative applications of the theoretical model developed in this paper are provided using British and Indonesian oil data. The application using British data focuses on the impact of North Sea Oil on GNP and NNP between 1976 and 1995, while the Indonesian application replicates Repetto et al.'s (1989) study. In both cases, it is shown that the volatility of NNP may be dramatically reduced when unexpected capital gains are excluded from depletion.

2. Some Conceptual Issues

(i) Valuing Assets

Throughout this paper, all prices and values are measured in constant dollars. Also, all prices and the interest rate are treated as exogenous. In this sense, the analysis is directed primarily towards small open economies.

Consider a stock of assets at the beginning of period t . $R_{t,t+k+i}$ denotes the receipt earned from this stock of assets in period $t+k+i$ assuming that none of the receipts earned between periods t and $t+k+i$ are reinvested in the stock of assets. $V_{t,t+k}$ denotes the value of the stock of assets existing at the beginning of period t at a later date $t+k$ assuming that none of the receipts earned between periods t and $t+k$ are reinvested. $V_{t,t+k}$ is equal to the discounted stream of future receipts, $R_{t,t+k+i}$, from period $t+k$ onwards:⁹

$$V_{t,t+k} \equiv \sum_{i=0}^{\infty} \left[\prod_{j=0}^i \left(\frac{1}{1+r_{t+k+j}} \right) R_{t,t+k+i} \right], \quad (1)$$

where r_t is the real interest rate in period t . If the formula for $V_{t,t+k}$ in (1) is written out in full for the cases where $k=0$ and $k=1$, it can be seen that V_{tt} and $V_{t,t+1}$ are related as follows:

$$V_{t,t+1} = (1+r_t)V_{tt} - R_{tt}. \quad (2)$$

The value of the actual stock of assets at the start of period $t+k$, namely, $V_{t+k,t+k}$ will not be the same as $V_{t,t+k}$ when some of the receipts earned between periods t and $t+k$ are reinvested, or if some of the assets are sold. For the case where $k=1$, the amount of this investment is determined by the difference between receipts R_{tt} and consumption C_t in period t . Thus,

$$V_{t+1,t+1} = V_{t,t+1} + R_{tt} - C_t, \quad (3)$$

$(R_{tt} - C_t)$ being the amount reinvested. Combining (2) and (3), it follows that

$$V_{t+1,t+1} = (1+r_t)V_{tt} - C_t. \quad (4)$$

⁹It should be noted that whether or not receipts are reinvested from period $t+k$ onwards has no effect on $V_{t,t+k}$.

To simplify the notation for the remainder of the paper, in cases where $k = 0$, we will write V_t and R_t , respectively, in place of V_{tt} and R_{tt} . Using this notation, rearranging (2), it follows that

$$r_t V_t = R_t + V_{t,t+1} - V_t. \quad (5)$$

Similarly, rearranging (4), it follows that

$$r_t V_t = C_t + V_{t+1} - V_t. \quad (6)$$

As is shown below, these two expressions for the interest earned on a stock of assets play an important role in the measurement of income.

(ii) Income Under Perfect Foresight

The main purpose of income is to provide guidance to households or other economic units, including government, on the rate at which they can afford to consume when there is uncertainty about future resources. As a point of departure, consider the widely quoted definition of income given in Hicks's *Value and Capital*:

[D]efine a man's income as the maximum value that he can consume during a week, and still expect to be as well off at the end of the week as he was at the beginning. [Hicks (1946), Second Edition, p. 172]

This definition is not sufficiently precise as it stands. It nests two income concepts that Hicks referred to as income no. 1 and no. 2. Hicksian income no. 1 is the maximum level of consumption that will maintain wealth intact, while Hicksian income no. 2 is the maximum sustainable level of consumption. These two concepts coincide only when the interest rate remains fixed over time [see Hicks (1946), pp. 173-4].

More formally, Hicksian income no. 1, denoted here by Y_t , is defined as follows:

$$Y_t \equiv \text{Max}\{C_t : V_{t+1} \geq V_t\}. \quad (7)$$

Setting $V_{t+1} = V_t$ in (6), it follows from (7) that

$$Y_t = r_t V_t. \quad (8)$$

Substituting (5) and (6) into (8), it can be seen that Hicksian income no. 1 can also be written as follows:

$$Y_t = R_t + V_{t,t+1} - V_t = C_t + V_{t+1} - V_t. \quad (9)$$

Hicksian income no. 1, therefore, is equal to total receipts R_t plus $(V_{t,t+1} - V_t)$, the total capital gains on the stock of assets existing at the beginning of the period. Equation (9) also shows that income is equal to consumption C_t plus $(V_{t+1} - V_t)$, the actual change in the value of the stock of assets. The latter reflects the effects of investment or disinvestment as well as capital gains. This change can be decomposed into the capital gain on the stock held at the start of the period, $(V_{t,t+1} - V_t)$, and net investment during the period, $(V_{t+1} - V_{t,t+1})$.

By contrast, Hicksian income no. 2, denoted by $\hat{Y}_t$, is defined as follows:

$$\hat{Y}_t \equiv \text{Max} \left\{ C_t : \sum_{i=0}^{\infty} \left[\prod_{j=0}^i \left(\frac{1}{1 + r_{t+j}} \right) C_t \right] \leq V_t \right\},$$

which reduces to

$$\hat{Y}_t = V_t / \sum_{i=1}^{\infty} \left[\prod_{j=0}^i \left(\frac{1}{1 + r_{t+j}} \right) \right]. \quad (10)$$

$\hat{Y}_t$ excludes part of the capital gain (loss) arising from interest rate changes. Hicks's two concepts of income are equivalent only when the interest rate does not change over time. In this case, both Y_t and $\hat{Y}_t$ reduce to rV_t . A rate of consumption equal to rV_t maintains wealth intact and is sustainable indefinitely if r does not change.¹⁰

¹⁰Equation (9) shows that if there is no capital gain, Hicksian income no. 1 equals consumption plus net investment. Weitzman's (1976) seminal paper on national accounting showed that, under the assumption of a constant interest rate in an economy with a single consumption and investment good, national income, defined as the sum of consumption and net investment, can be interpreted as a measure of welfare. In our context, what is interesting is the absence of capital gains in Weitzman's welfare measure. A natural way of incorporating capital gains into Weitzman's model is by assuming that the price of capital changes over time in a specified way (as for example might be the case for an open economy exporting a non-renewable natural resource whose price follows the Hotelling rule) rather than being determined endogenously. In this case, the price of capital itself becomes a state variable in the Hamiltonian, and hence the resulting capital gains are part of income (and welfare).

(iii) *Income Under Uncertainty*

Further complications arise when we allow for uncertainty. Here we will consider generalizations under uncertainty of Hicksian income no. 1, since it is the simpler concept. It is worth emphasizing at this point that the choice between Hicksian income no. 1 and no. 2 does not affect the substance of this paper which focuses on the treatment of unexpected capital gains. Furthermore, in sections 3, 4 and 5 it is assumed that the interest rate does not vary over time. Under this assumption, as noted earlier, both income concepts are the same. The concept of the maximum sustainable level of consumption (i.e., Hicksian income no. 2) will be appealed to frequently in these sections.

When there is uncertainty the estimated value of a person's wealth at any point of time depends on the time at which the estimate is made. Define $E_s V_t$ as the expectation at time s of the value of the stock of assets existing at the beginning of period t . Time s can precede, coincide with or follow t . Since the stream of receipts $(R_s, R_{s+1}, R_{s+2}, \dots)$ can extend indefinitely into the future, this implies that V_t , in general, is never known for certain, even if $s > t$.

Haig-Simons Income

The Haig (1921)-Simons (1938) definition of income is widely used by economists [see, for example, McElroy (1976) and Eisner (1988, 1990)]. It is an *ex post* version of Hicksian income no. 1. Haig-Simons income, denoted here by Y_t^{HS} , is defined as follows:

$$Y_t^{HS} \equiv \text{Max}\{C_t : E_{t+1}V_{t+1} \geq E_t V_t\}. \quad (11)$$

Hill and Hill (2003) show that Haig-Simons income can be rewritten as follows:

$$Y_t^{HS} = C_t + E_{t+1}V_{t+1} - E_t V_t = R_t + E_{t+1}V_{t,t+1} - E_t V_t. \quad (12)$$

In other words, Haig-Simons income can be expressed as the sum of consumption plus the actual change in wealth over the period, or as the sum of receipts and the actual change in the value of the stock of assets existing at the start of the period.

Haig-Simons income equals the amount a person can consume in period t and be as well off at the beginning of period $t + 1$ as he thought he was at the beginning of period t . The basic flaw in the concept is that a prudent consumer has no reason to wish to preserve $E_t V_t$ intact as soon as events have shown it to be wrong.

Suppose the price of oil rises unexpectedly in period t . Assuming this price rise is perceived as permanent, Haig-Simons includes the whole increase in the value of oil reserves in income for period t . If households and the government in an oil rich country use the Haig-Simons definition of income to guide their consumption decisions, they would be encouraged to spend the whole windfall in the current period in order to return wealth to its initial level. Clearly this level of consumption could not be maintained indefinitely into the future and hence is not sustainable. Haig-Simons breaks the link between income and sustainability, since sustainability is a forward looking concept while Haig-Simons is backward looking. In addition, such a consumption strategy would be quite arbitrary as it would make the rate of consumption depend on the length of the accounting period (of whose existence households and government may not even be aware).

Generalized-Hicksian Income

None of the objections just raised to the Haig-Simons concept of income apply to the ‘generalized-Hicksian’ income concept defined in Hill and Hill (2003). Generalized-Hicksian income estimates wealth consistently at both the beginning and the end of the period on the basis of the same information and expectations. The expectation at time s of income in period t is

$$E_s Y_t \equiv \text{Max}\{E_s C_t : E_s V_{t+1} \geq E_s V_t\}. \quad (13)$$

Hill and Hill (2003) show that $E_s Y_t$ can be rewritten as follows:

$$E_s Y_t = E_s R_t + E_s V_{t,t+1} - E_s V_t = E_s C_t + E_s V_{t+1} - E_s V_t. \quad (14)$$

It should be noted that R_t and C_t in (14) are known if $s > t$. Income as defined in (13)

depends on the time, s , at which it is estimated. Two cases of particular interest are the start and the end of the accounting period. When $s = t$, $E_t Y_t$ is the *ex ante* definition of income discussed in Hicks (1946, p. 172). Also, it is worth noting that Friedman's (1957) concept of permanent income is essentially the same as *ex ante* Hicksian income [see Eisner (1990, p. 1180)].

$$E_t Y_t = \text{Max}\{C_t : E_t V_{t+1} \geq E_t V_t\}, \quad (15)$$

so that

$$E_t Y_t = E_t(r_t V_t) = E_t R_t + (E_t V_{t,t+1} - E_t V_t) = E_t C_t + (E_t V_{t+1} - E_t V_t). \quad (16)$$

Ex ante income, $E_t Y_t$, is the maximum amount that a person can plan to consume in period t and expect wealth at the end of the period to be the same as estimated at the start of the period. Hicks argues that this is the concept of income relevant to consumer behavior, as does Friedman (1957) in his permanent income hypothesis.

The problem with $E_t Y_t$ is that it can be computed at the beginning of period t and hence is only a forecast. For this reason, the corresponding *ex post* concept of income obtained by setting $s = t + 1$ is preferable in an accounting context.

$$E_{t+1} Y_t = \text{Max}\{C_t : E_{t+1} V_{t+1} \geq E_{t+1} V_t\}, \quad (17)$$

so that

$$E_{t+1} Y_t = r_t(E_{t+1} V_t) = R_t + (E_{t+1} V_{t,t+1} - E_{t+1} V_t) = C_t + (E_{t+1} V_{t+1} - E_{t+1} V_t). \quad (18)$$

Hartwick and Hageman (1993) also advocate using an *ex post* income concept of this type to deal with unexpected capital gains, particularly those caused by price shocks.

If one is analyzing data from the past that feature a structural break because of a then-unanticipated shock, one might use post-discovery prices in the pre-discovery periods near the date of the unanticipated discovery or shock to smooth out calculations of true economic depreciation or to obtain more accurate benefit-cost estimates. [Hartwick and Hageman (1993, p. 228)]

It must be emphasized that measuring income *ex post* does not mean that all uncertainty has been resolved but simply that measurement takes place after the end of the period when actual receipts and consumption in period t are known. *Ex post* income is still a forward looking measure. It depends on expectations of future receipts held at the end of the period. It should also be emphasized that *ex post* income, as defined in (17) and (18), is not the income concept labelled as *ex post* by Hicks in *Value and Capital*. Hicks chose to identify *ex post* income with Haig-Simons, which he dismissed on the grounds that it must contain unexpected capital gains whereas “The income which is relevant to conduct must always exclude windfall gains” [Hicks (1946), p. 179]. It is shown below that, unlike Haig-Simons income, *ex post* income excludes unexpected capital gains.

(iv) *Capital Gains*

Following Hill and Hill (2003), the capital gain on a given stock of assets is defined as the change in its value between two points of time. $G_{(t,t+k)}$ is used to denote the capital gain accruing between the start of period t and the start of period $t + k$ on the stock existing at the start of period t .

$$G_{(t,t+k)} \equiv E_{t+k}V_{t,t+k} - E_tV_t \quad (19)$$

Defined this way, capital gains can be divided into expected and unexpected components. The expected capital gain accruing between the start of period t and $t + k$, based on expectations at time s , is

$$E_sG_{(t,t+k)} \equiv E_sV_{t,t+k} - E_sV_t. \quad (20)$$

An unexpected capital gain, denoted here by UG , occurs when the estimated value of the stock of assets at some point of time is changed as a result of revised expectations. The unexpected capital gain on the stock at time t resulting from new information gained during the time interval (h, l) , where $h \leq l$, is defined as follows:

$$U_{(h,l)}G_t \equiv E_lV_t - E_hV_t. \quad (21)$$

Of particular interest are the cases where $s = t$ or $s = t + k$ in (20), and $h = t$ and $l = t + k$ in (21). For these cases, it is possible to decompose a capital gain into its expected and unexpected components (in two different ways).

$$G_{(t,t+k)} = E_t G_{(t,t+k)} + U_{(t,t+k)} G_{(t+k)} = E_{t+k} G_{(t,t+k)} + U_{(t,t+k)} G_t \quad (22)$$

It can now be seen that Haig-Simons income can be written as the sum of receipts and capital gains, i.e.:

$$Y_t^{HS} = R_t + E_{t+1} V_{t,t+1} - E_t V_t = R_t + G_{(t,t+1)}. \quad (23)$$

Similarly, generalized-Hicksian income can be written as the sum of expected receipts and expected capital gains, i.e.:

$$E_s Y_t = E_s R_t + E_s V_{t,t+1} - E_s V_t = E_s R_t + E_s G_{(t,t+1)}. \quad (24)$$

This in turn implies that *ex post* income and Haig-Simons income are related as follows:

$$\begin{aligned} Y_t^{HS} &= R_t + E_{t+1} V_{t,t+1} - E_t V_t = (R_t + E_{t+1} V_{t,t+1} - E_{t+1} V_t) \\ &\quad + (E_{t+1} V_t - E_t V_t) = E_{t+1} Y_t + U_{(t,t+1)} G_t. \end{aligned} \quad (25)$$

Haig-Simons income is equal to *ex post* income plus the unexpected capital gain or loss in period t resulting from new information that emerged during period t .¹¹

(v) Depletion of Natural Assets

Following Hotelling (1925), and assuming perfect foresight, the depletion of a natural asset such as an oil field during period t is defined as the decrease in its value between the beginning and end of the period. Alternatively, depletion can be thought of as that part of receipts that are not income [see El Serafy (1989)]. These two definitions are equivalent. Although straightforward under perfect foresight, the concept of depletion

¹¹It should be noted that although *ex post* income, $E_{t+1} Y_t$, excludes unexpected capital gains in period t , the interest earned on these gains, $r_t U_{(t,t+1)} G_t$, is included in *ex post* income. This point is made clear in equation (37).

becomes more complex when one allows for uncertainty. In fact, each concept of income has its own corresponding definition of depletion. The concept of depletion consistent with Haig-Simons income is denoted here by D_t^{HS} .

$$D_t^{HS} = E_t V_t - E_{t+1} V_{t+1} \quad (26)$$

Comparing (26) with (19) shows that $D_t^{HS} = -G_{(t,t+1)}$. In other words, Haig-Simons depletion equals the total capital loss in period t . Haig-Simons income and depletion are related as follows:

$$Y_t^{HS} = R_t - (E_t V_t - E_{t+1} V_{t+1}) = R_t - D_t^{HS}. \quad (27)$$

The concept of depletion consistent with generalized-Hicksian income is denoted here by $E_s D_t$. We will refer to the cases where $s = t$ and $s = t + 1$ here as *ex ante* and *ex post* depletion, respectively.

$$E_s D_t = E_s V_t - E_s V_{t+1} \quad (28)$$

Generalized-Hicksian income and depletion are related as follows:

$$E_s Y_t = E_s R_t - (E_s V_t - E_s V_{t+1}) = E_s R_t - E_s D_t. \quad (29)$$

Comparing (28) with (20) shows that $E_s D_t = -E_s G_{(t,t+1)}$. Returning to the example of an oil field, this result implies that generalized-Hicksian depletion will be unaffected by unexpected changes in the price of oil.

The relationship between Haig-Simons depletion and *ex post* depletion is given below in (30). Since depletion is defined as a *decrease* in the value of an asset over time, it is convenient (following Hotelling) to multiply through by minus 1 in order to reverse the signs in (30).

$$\begin{aligned} -D_t^{HS} &= E_{t+1} V_{t+1} - E_t V_t = (E_{t+1} V_{t+1} - E_{t+1} V_t) - (E_t V_t - E_{t+1} V_t) \\ &= -E_{t+1} D_t + U_{(t,t+1)} G_t \end{aligned} \quad (30)$$

Hence *ex post* depletion excludes unexpected capital gains or losses, whereas the Haig-Simons definition includes them.

At this point it is also useful to discuss briefly two other depletion formulae that have received attention in the environmental accounting literature. The first, proposed by El Serafy (1989), assumes constant receipts for a finite number of periods (say T) after which the resource is exhausted. Given this assumption, it follows that for $1 \leq t \leq T$:

$$V_t = \frac{R}{1+r} + \frac{R}{(1+r)^2} + \cdots + \frac{R}{(1+r)^{T+1-t}} = \frac{R}{r} \left[1 - \left(\frac{1}{1+r} \right)^{T+1-t} \right],$$

which in turn implies that

$$D_t = V_t - V_{t+1} = \frac{R}{(1+r)^{T+1-t}}.$$

El Serafy also discusses how this formula can be adjusted to take account of discoveries of new stock. He argues that discoveries should be viewed as simply increasing the number of periods over which constant receipts are paid. For example, suppose enough barrels of oil are discovered in period t to allow the current rate of extraction to be maintained for X more periods than previously anticipated. Then recorded depletion in period t will be $R/(1+r)^{T+X+1-t}$, which is less than $R/(1+r)^{T+1-t}$ (i.e., the discovery causes measured depletion to fall). Unexpected price shocks, meanwhile, can be viewed as changing R . For example, suppose the price of oil rises in period t . For an oil-rich country, assuming the rate of extraction does not fall in response to the price rise, this means $R_t > R_{t-1}$. Hence depletion in period t will be $R_t/(1+r)^{T+1-t}$, which is greater than $R_{t-1}/(1+r)^{T+1-t}$. In other words, rather than observing a large negative spike, recorded depletion actually rises in an oil-rich country when the price of oil rises.¹² This is because the extracted oil is now more valuable.

The second alternative depletion formula is the total Hotelling rent formula proposed by Hartwick (1989). Under the assumption that marginal receipts rise at the rate of interest over time [i.e., the Hotelling (1931) rule], depletion equals total Hotelling rent

¹²The same pattern is observed for *ex post* Hicksian income, as is discussed later in the paper.

which is the product of marginal receipts and the quantity extracted (i.e., for a price taking firm $D_t = [P_t - MC_t(Q)]Q_t$).¹³ In the presence of discoveries, Hartwick and Hageman (1993) show that the formula for total Hotelling rent (i.e., depletion) should be modified as follows:

$$D_t = (P_t - MC_t(Q))Q_t - MC_t(Z)Z_t,$$

where Z_t denotes the quantity of the resource discovered in period t . In an example in their paper, Hartwick and Hageman handle price shocks by using the average of the prices prevailing at the beginning and end of the period, although at another point in the same paper they advocate using only *ex post* prices after a shock (see earlier quote).

We conclude this section with an informal comparison of the impact of discoveries of new stocks of nonrenewable resources on each of the depletion formulae discussed here. In the next section, a more detailed comparison is made between *ex post* Hicksian income and Haig-Simons income.

Suppose a new stock of an exhaustible resource is discovered during period t . How is each measure of depletion affected? Haig-Simons depletion, D_t^{HS} , is reduced by the full value of the discovery, which in some cases may cause depletion to become negative. *Ex ante* depletion, $E_t D_t$, is unaffected by the discovery since it occurs after the beginning of the period. Assuming receipts in period t are unaffected by the discovery, *ex post* depletion, $E_{t+1} D_t$, will fall since GNP is unaffected, while NNP rises. However, *ex post* depletion falls much less than Haig-Simons depletion. Depletion, measured using El Serafy's formula, will also fall by a relatively small amount, and by construction cannot go negative. Finally, depletion measured using Hartwick and Hageman's formula also falls, although the magnitude of the fall will depend on the relative size of the marginal cost of discovery, $MC_t(Z)$, and the marginal cost of extraction, $MC_t(Q)$. If $MC_t(Z)$ is significantly less than $MC_t(Q)$, as it is in the example in Hartwick and Hageman (1993,

¹³The assumption that marginal receipts rise at the rate of interest over time, makes it possible to measure depletion without ever valuing the resource stock in a particular period.

p. 226), then the fall in depletion will be considerably smaller than that observed using Haig-Simons depletion. In other words, the depletion formulae of El Serafy and Hartwick and Hageman, like *ex post* income, also tend to dampen the impact of unexpected capital gains on depletion and NNP.

3. The Impact of Unexpected Capital Gains on Depletion, NNP and GNP

The two main sources of unexpected capital gains on nonrenewable natural resource assets, such as oil, are changes in price and the discovery of new deposits.¹⁴ Technological progress and changes in the interest rate also generate capital gains. The implications of technological progress and changes in the interest rate for sustainability are discussed in Weitzman (1997) and Asheim (1997).

Consider the impact on the GNP and NNP of an oil exporting country of an unexpected change in the price (or stock) of oil. If the shock occurs during period t , its impact on expectations of GNP in period t is given by

$$\Delta E_{t+1}GNP_t = GNP_t - E_tGNP_t = R_t - E_tR_t. \quad (31)$$

It is assumed in (31) that GNP in period t , GNP_t , is known with certainty after the end of period t .

Before turning to NNP it is first useful to look at depletion. To simplify the analysis, it will be assumed for the remainder of the paper that the real interest rate r does not vary over time.¹⁵ Also, it is assumed that the oil is not sold in a futures market before it is extracted. Nor are receipts used to buy more oil. Given these constraints, the first subscript on R and V can be dispensed with (i.e., $V_{t,t+k} = V_{t+k}$ and $R_{t,t+k} = R_{t+k}$).¹⁶

¹⁴Actually, the treatment of discoveries of new deposits is not clear-cut. Since new discoveries are a direct consequence of exploration activities, they could be classified as gross capital formation instead of as capital gains. This issue is discussed in greater detail in Nordhaus and Kokkelenberg (1999) and Hill and Hill (2003).

¹⁵As discussed earlier, under this assumption Hicksian income no. 1 and 2 are equivalent.

¹⁶This does not preclude some of the receipts being invested in the infrastructure of the oil field.

The expected value of the country's stock of oil at the beginning of period t , based on expectations at time s , can be written as follows:

$$E_s V_t = \sum_{i=0}^{\infty} \left[\left(\frac{1}{1+r} \right)^{i+1} E_s R_{t+i} \right]. \quad (32)$$

It now follows from (5), when suitably generalized to allow for uncertainty, that

$$E_{t+1} V_{t+1} = (1+r)E_{t+1} V_t - R_t.$$

Therefore, using (28), *ex post* depletion of the stock of oil in period t is

$$E_{t+1} D_t = E_{t+1} V_t - E_{t+1} V_{t+1} = R_t - rE_{t+1} V_t.$$

Similarly, *ex ante* depletion in period t is

$$E_t D_t = E_t V_t - E_t V_{t+1} = E_t R_t - rE_t V_t.$$

Now let $\Delta E_{t+1} D_t$ denote the difference between *ex post* and *ex ante* depletion in period t .

$$\begin{aligned} \Delta E_{t+1} D_t &= E_{t+1} D_t - E_t D_t = (R_t - rE_{t+1} V_t) - (E_t R_t - rE_t V_t) \\ &= R_t - E_t R_t - r(E_{t+1} V_t - E_t V_t) \end{aligned} \quad (33)$$

Also, let ΔD_t^{HS} denote the difference between Haig-Simons and *ex ante* depletion in period t .

$$\begin{aligned} \Delta D_t^{HS} &= D_t^{HS} - E_t D_t = E_t V_t - E_{t+1} V_{t+1} - E_t R_t + rE_t V_t \\ &= R_t - E_t R_t - (1+r)(E_{t+1} V_t - E_t V_t) \end{aligned} \quad (34)$$

$\Delta E_{t+1} D_t$ and ΔD_t^{HS} represent two different formulae for measuring the impact of an unexpected shock during period t on depletion in period t . In particular, it should be noted that if nothing unexpected happens during period t , then $\Delta E_{t+1} D_t = \Delta D_t^{HS} = 0$.

Each definition of depletion has its own corresponding definition of NNP. The definition consistent with the Haig-Simons concept of income, denoted here by NNP_t^{HS} , is given by

$$NNP_t^{HS} = GNP_t - D_t^{HS}. \quad (35)$$

The generalized-Hicksian definition of NNP is given by

$$E_s NNP_t = E_s GNP_t - E_s D_t. \quad (36)$$

A distinction can be drawn between *ex ante* NNP, $E_t NNP_t$, and *ex post* NNP, $E_{t+1} NNP_t$. Let $\Delta E_{t+1} NNP_t$ denote the difference between *ex post* and *ex ante* NNP in period t , as defined in (36).

$$\begin{aligned} \Delta E_{t+1} NNP_t &= E_{t+1} NNP_t - E_t NNP_t = (GNP_t - E_{t+1} D_t) - (E_t GNP_t - E_t D_t) \\ &= \Delta E_{t+1} GNP_t - \Delta E_{t+1} D_t = r(E_{t+1} V_t - E_t V_t) = rU_{(t,t+1)} G_t, \end{aligned} \quad (37)$$

where $U_{(t,t+1)} G_t$ is the unexpected capital gain in period t as defined in (21). In other words, unexpected capital gains in period t are excluded from *ex post* NNP, although the income stream they generate, $rU_{(t,t+1)} G_t$, is included. In contrast, as shown below in (38), the Haig-Simons formula includes in NNP both unexpected capital gains in period t and the income stream they generate.

$$\begin{aligned} \Delta NNP_t^{HS} &= NNP_t^{HS} - E_t NNP_t = (GNP_t - D_t^{HS}) - (E_t GNP_t - E_t D_t) \\ &= \Delta E_{t+1} GNP_t - \Delta D_t^{HS} = (1+r)(E_{t+1} V_t - E_t V_t) = (1+r)U_{(t,t+1)} G_t \end{aligned} \quad (38)$$

The NNP_t^{HS} formula's treatment of unexpected capital gains is analogous to treating lottery winnings as income. As Hicks observed, this amounts to confusing the concepts of income and capital.

What can be deduced about the relative magnitudes of $\Delta E_{t+1} GNP_t$, $\Delta E_{t+1} NNP_t$ and ΔNNP_t^{HS} ? To answer this question we must impose some structure on expectations of future receipts. The approach followed here can be contrasted with that of El Serafy (1989). By assuming that the receipts generated each period are the same until the resource stock is exhausted, as discussed in the previous section, El Serafy derives a simple formula for depletion. In the next section it is shown that, by assuming a geometric path for expected future receipts, an alternative but equally simple depletion formula – see equation (52) – can be derived. The focus here, however, is on comparing

the relative magnitudes of $\Delta E_{t+1}GNP_t$, $\Delta E_{t+1}NNP_t$ and ΔNNP_t^{HS} . The assumption of a geometric path for expected future receipts proves very useful here as well.¹⁷

If expectations of future receipts follow a geometric path, this means that

$$E_s R_\tau = \alpha^{\tau-s+1} R_{s-1} \quad \forall \tau \geq s. \quad (39)$$

Although this specification may seem restrictive, it is probably sufficient for most cases. Given the huge amount of uncertainty over the future price of oil, the expected path of future receipts is unlikely to be very elaborate.

A direct consequence of (32) and (39) is that $E_t V_t$ and $E_{t+1} V_t$ reduce to geometric progressions which converge as long as $\alpha < (1 + r)$.

$$E_t V_t = \frac{\alpha R_{t-1}}{1 + r - \alpha} \quad (40)$$

$$E_{t+1} V_t = \frac{R_t}{1 + r - \alpha} \quad (41)$$

More generally,

$$E_s V_t = \sum_{\tau=t}^{s-1} \left\{ \left(\frac{1}{1+r} \right)^{\tau-t+1} R_\tau \right\} + \left(\frac{\alpha}{1+r-\alpha} \right) \left(\frac{1}{1+r} \right)^{s-t} R_{s-1}. \quad (42)$$

Combining (40) and (41), it follows that the unexpected capital gain, $U_{(t,t+1)} G_t$, simplifies to

$$U_{(t,t+1)} G_t = E_{t+1} V_t - E_t V_t = \left(\frac{R_t - \alpha R_{t-1}}{1 + r - \alpha} \right). \quad (43)$$

Now, substituting (39) and (43) into (33) and (34), respectively, it follows that

$$\Delta E_{t+1} D_t = \left(\frac{1 - \alpha}{1 + r - \alpha} \right) (R_t - \alpha R_{t-1}), \quad (44)$$

$$\Delta D_t^{HS} = - \left(\frac{\alpha}{1 + r - \alpha} \right) (R_t - \alpha R_{t-1}). \quad (45)$$

A comparison of (44) with (45) reveals that, when α is less than one, $\Delta E_{t+1} D_t$ and ΔD_t^{HS} have opposite signs. Therefore, if $R_t > \alpha R_{t-1}$, as is likely for an oil exporting

¹⁷This assumption has also been widely used in the capital theory literature, where it is often assumed that the receipts earned on an asset decline geometrically [see Jorgenson (1963) and Jorgenson, Hunter and Nadiri (1970).]

country when the price of oil rises unexpectedly, then depletion falls according to D_t^{HS} , but rises according to $E_{t+1}D_t$. $\Delta D_t^{HS} < 0$ because the value of the stock of oil has risen. Conversely, $\Delta E_{t+1}D_t > 0$ because the value of the oil being extracted has now increased (assuming the rate of extraction does not fall). $\Delta E_{t+1}GNP_t$ equals the full amount of the increase in receipts, while $\Delta E_{t+1}NNP_t$ equals only the interest earned on the increased valuation of the stock. The rise in GNP is larger than the rise in NNP, and hence the gap between GNP and NNP (i.e., depletion) must have risen.

Substituting (39) and (43) into (37) and (38) generates the following formulae for NNP:

$$\Delta E_{t+1}NNP_t = \left(\frac{r}{1+r-\alpha} \right) (R_t - \alpha R_{t-1}), \quad (46)$$

$$\Delta NNP_t^{HS} = \left(\frac{1+r}{1+r-\alpha} \right) (R_t - \alpha R_{t-1}). \quad (47)$$

Finally, substituting (39) into (31), we obtain that

$$\Delta E_{t+1}GNP_t = GNP_t - E_t GNP_t = R_t - \alpha R_{t-1}. \quad (48)$$

A comparison of (46), (47) and (48) reveals that

$$0 < \alpha < 1 \Rightarrow |\Delta E_{t+1}NNP_t| < |\Delta E_{t+1}GNP_t| < |\Delta NNP_t^{HS}|, \quad (49)$$

$$\alpha = 1 \Rightarrow |\Delta E_{t+1}NNP_t| = |\Delta E_{t+1}GNP_t| < |\Delta NNP_t^{HS}|, \quad (50)$$

$$1 < \alpha < 1+r \Rightarrow |\Delta E_{t+1}GNP_t| < |\Delta E_{t+1}NNP_t| < |\Delta NNP_t^{HS}|. \quad (51)$$

Therefore, for all permissible values of α , it follows from (49), (50) and (51) that NNP_t^{HS} is more volatile than both GNP_t and $E_{t+1}NNP_t$ in period t . (The geometric progressions do not converge if $\alpha \geq 1+r$.) Which is more volatile of GNP_t and $E_{t+1}NNP_t$ depends on the value of α . If as in (49) $\alpha < 1$, then $E_{t+1}NNP_t$ is less volatile than GNP_t , while if as in (51), $1 < \alpha < 1+r$, then this result is reversed. For nonrenewable resources we might expect α to be very slightly less than one, since the stock of nonrenewable resources is finite, and hence the amount extracted must eventually decline. Also, rising costs of extraction, as the more profitable deposits are exhausted,

and increased international competition may cause receipts to decline. Technological progress, however, may prevent this from happening. Indeed, the declining long run real price trend of practically all nonrenewable resources [see Adelman (1990)] is probably attributable to a combination of technological progress and increased international competition. It is less clear what has happened to receipts. Irrespective of the exact value of α , as long as it is close to one, this implies that, contrary to the results of most empirical studies, NNP should not be systematically more volatile than GNP.

4. The Depletion of North Sea Oil and its Impact on British NNP

This section applies the theoretical framework developed in the previous sections to the depletion of British North Sea Oil fields between 1976 and 1995. In particular, the sensitivity of measured depletion and NNP to the method of measurement is examined. Three sets of NNP estimates are provided: NNP_t^{HS} , $E_{t+1}NNP_t$ and $E_{96}NNP_t$.

It should be emphasized that the empirical results obtained here are illustrative. No attempt has been made to estimate the stock of oil reserves, and the rate at which this stock is extracted. Rather, given that income, correctly defined, is a forward-looking concept, our emphasis is on modelling expectations of future receipts. It is assumed that, in each period, receipts are expected to follow a geometric path. The expected path is updated each period as new information becomes available. Beliefs about the sustainability of current rates of extraction, relative to known reserves, are captured by the parameter α in the geometric progression. Although this formulation is clearly a simplification on reality, given the huge amount of uncertainty regarding the future path of the price of oil, the stock of oil *in situ* and the cost of extracting it, it seems unlikely that expectations of future receipts can get very much more precise than this. Therefore, the results obtained here are at least indicative of the results that would be obtained in a more detailed comparison.

A similar exercise was previously undertaken by Aslaksen et al. (1990) for Norway over the period 1973 to 1989, with the important difference that they focused on compar-

isons between *ex ante* income, $E_t NNP_t$ and a measure that includes unexpected capital gains (i.e., Haig-Simons income). In contrast, we compare *ex post* income, $E_{t+1} NNP_t$, with Haig-Simons income. This distinction is important since *ex post* and Haig-Simons income are computed based on the same information, while *ex ante* and Haig-Simons income are not. Furthermore, income in a national accounts context cannot be measured until the end of the accounting period. This is why the relevant comparison is between *ex post* and Haig-Simons income. Aslaksen et al. also differs from our paper in the approach used to estimate each income concept and unexpected capital gains.

The North Sea Oil data are shown in Table 1. The quantity of crude oil extracted, q_t^O , is measured in millions of tonnes, and the total oil revenue, TR_t^O , in millions of 1990 pounds. The price index, p_t^O , is obtained implicitly as the ratio of total revenue to quantity extracted. Hence the price index depicts the average price of a tonne of crude oil in 1990 pounds. The quantity of natural gas extracted, q_t^G , is measured in billions of cubic metres, and total gas revenue, TR_t^G , in millions of 1990 pounds. The price index, p_t^G , is again obtained implicitly and depicts the average price of a thousand cubic metres in 1990 pounds. The total revenue, TR_t , is the total revenue obtained from oil, gas, and other sources. Hence TR_t exceeds slightly the sum of TR_t^O and TR_t^G . The total cost, TC_t , consists of operating costs for both oil and gas. The receipt, R_t , is the difference between TR_t and TC_t , and is measured in millions of 1990 pounds.¹⁸ Investment, I_t ,

¹⁸All quantity, revenue, and cost data were obtained from various issues of the Digest of United Kingdom Energy Statistics, published by the Department of Trade and Industry. For example, in the 1996 issue, revenue and cost data are given in Table 36 on page 84, while extraction data are given in Table 29, page 75. Data on rates of extraction before 1976 are also available in the Digest of United Kingdom Energy Statistics in Table 38 of the 1979 issue. Although offshore production of crude oil only started in 1975, the extraction of onshore crude oil started in the 1960s. From 1975 onwards, onshore extraction is insignificant compared with offshore extraction. Gas revenue data for 1975 are obtained from Johnson (1978), Table 3.4, page 90. Oil revenue for 1975 is obtained by multiplying the price of crude oil by the quantity extracted. The 1975 price data are taken from Allsopp and Rhys (1989), Table 19.2, page 380. Finally, the cost data for 1975 are taken from Johnson (1978), Table 5.3, page 157. All the revenue, cost and price data were converted into 1990 pounds using the GDP

equals total expenditure on development and exploration. Finally, K_t is the value of the total capital stock. It is computed assuming a fixed rate of depreciation, δ , of 6% per year.¹⁹ Therefore, $K_{t+1} = (1 - \delta)K_t + I_t$.

Insert Table 1 Here

Table 2 shows estimates of depreciation, depletion and NNP. As discussed above, the rate of depreciation on the capital stock of the oil and gas industry is assumed to be 6%. Hence depreciation is given by δK_t where $\delta = 0.06$. Three different formulae, however, are used to compute depletion. These are Haig-Simons's depletion, D_t^{HS} defined in (30), and the generalized-Hicksian depletion formula defined in (28) for the cases where $s = t + 1$ and $s = 1996$, respectively (i.e., $E_{t+1}D_t$ and $E_{96}D_t$). Given the additional assumptions that real interest rates are fixed and future receipts are expected to follow a geometric path, these three depletion formulae reduce to the expressions stated in (52), (53) and (54).

$$E_{t+1}D_t = E_{t+1}V_t - E_{t+1}V_{t+1} = \left(\frac{1}{1+r-\alpha}\right)R_t - \left(\frac{\alpha}{1+r-\alpha}\right)R_t = \left(\frac{1-\alpha}{1+r-\alpha}\right)R_t \quad (52)$$

$$\begin{aligned} D_t^{HS} &= E_tV_t - E_{t+1}V_{t+1} = \left(\frac{\alpha}{1+r-\alpha}\right)R_{t-1} - \left(\frac{\alpha}{1+r-\alpha}\right)R_t \\ &= \left(\frac{\alpha}{1+r-\alpha}\right)(R_{t-1} - R_t) \end{aligned} \quad (53)$$

$$\begin{aligned} E_sD_t &= E_sV_t - E_sV_{t+1} = R_t - rE_sV_t \\ &= R_t - r \left\{ \sum_{\tau=t}^{s-1} \left[\left(\frac{1}{1+r}\right)^{\tau-t+1} R_\tau \right] - \left(\frac{r\alpha}{1+r-\alpha}\right) \left(\frac{1}{1+r}\right)^{s-t} R_{s-1} \right\}. \end{aligned} \quad (54)$$

deflator in the United Kingdom National Accounts (the Blue Book), Table 1.1, on pages 24 and 25 of the 1997 issue, and pages 10 and 11 of the 1990 issue.

¹⁹This is the approximate average rate of depreciation of the capital stock in the mining and quarrying category (which includes oil and gas) in the United Kingdom National Accounts (Blue Book, 1997), published by the Office for National Statistics. Capital consumption by industry group is given in Table 14.2, p. 162, while the gross capital stock by industry group is given in Table 14.8, p. 167. The ratio of capital consumption to the gross capital stock is close to 0.06 for all the years in the tables.

As noted earlier, the depletion formula in (52) is a simple alternative to the one proposed by El Serafy (1989). El Serafy assumes constant receipts for a finite number of periods after which the resource is exhausted, while equation (52) assumes a geometric path for expected future receipts. Expectations are updated each period. Which assumption is preferable, if either, must be judged on a case by case basis.

Returning to equations (52), (53) and (54), by specifying values for α and r , depletion can now be computed using the information in Table 1. Estimates of NNP are then obtained by deducting depreciation and depletion from GNP. Since the focus here is on the impact of North Sea Oil on NNP, all other sources of depreciation and depletion in Great Britain are ignored. Three different sets of NNP estimates are derived corresponding to each of the three sets of depletion estimates. The results in Table 2 are obtained assuming that $r = 0.05$ and $\alpha = 1$, while in Table 3, corresponding estimates are obtained for the case where $r = 0.05$ and $\alpha = 0.95$.

Insert Table 2 Here

Insert Table 3 Here

It is noticeable that the first five observations of $E_{96}D_t$ in Table 2 and the first four in Table 3 are all negative. This is an example of negative depletion. It arises because rents in the mid 1970s are much lower than rents in the 1980s. Hence as we move forward in time, the higher rents in the 1980s are discounted less heavily, thus causing the net present value of the stock of oil to rise, even though some oil has been extracted. A second interesting feature in Table 2 is that the depletion estimates for $E_{t+1}D_t$ in Table 2 all equal zero. This is because when rents are expected to remain constant (i.e., $\alpha = 1$) the expected value of the resource at two different points in time, evaluated at the same point in time, must be the same.

The NNP and GNP series from Tables 2 and 3 are graphed, respectively, in Figures 1 and 2. As discussed above, when $\alpha = 1$, it follows that $E_{t+1}D_t = 0$, and hence $E_{t+1}NNP_t = GNP - \delta K_t$. The volatility of NNP_t^{HS} , however, is striking in Figure 1. Clearly, in this case NNP_t^{HS} is completely useless for policy purposes. In Figure 2,

NNP_t^{HS} is less volatile, since α is smaller. In fact, from (53) it can be seen that as α tends to zero, D_t^{HS} does likewise, and hence NNP_t^{HS} converges on $GNP_t - \delta K_t$. This, however, is just a result of the fact that when $\alpha = 0$, $E_t V_t$ and $E_{t+1} V_{t+1}$ both also equal zero. Clearly, the assumption of geometrically declining receipts becomes untenable when α is too far below one, unless the resource in question has already been almost completely depleted. Even in Figure 2, NNP_t^{HS} is too volatile to be of much use for policy purposes.

Insert Figure 1 Here

Insert Figure 2 Here

The volatility of NNP_t^{HS} is also dependent on the interest rate r . In particular, as r falls, NNP_t^{HS} becomes even more volatile. For example, when $r = 0.01$ and $\alpha = 1$ (not shown in the Tables), NNP_t^{HS} actually becomes negative in 1986, as a result of the collapse in the price of oil.

The best measure of NNP in both Tables 2 and 3 is provided by the $E_{96}NNP_t$ series, since it makes use of the most information, although it suffers from the disadvantage that it can only be calculated retrospectively in 1996. According to the $E_{96}NNP_t$ series, most of the depletion of North Sea Oil occurred between 1980 and 1985. This is because this is the period during which oil prices peaked, and hence receipts were highest.

It is also interesting to consider the impact of North Sea Oil on Britain's average growth rate between 1976 and 1995. The average annual growth rate of GNP over this period, $g(GNP)$, expressed as a percentage, is calculated as follows:

$$g(GNP) = 100 \left\{ \left(\frac{GNP_{1995}}{GNP_{1976}} \right)^{1/19} - 1 \right\}. \quad (55)$$

Average growth rates for NNP are calculated in an analogous manner. The results are shown in Table 4. A comparison of $g(GNP_t)$ and $g(E_{96}NNP_t)$ reveals that accounting for the depletion of North Sea Oil reduces the average annual real growth rate between 1976 and 1995 from 2.09% to about 1.93%. Although this may sound small, at its peak in 1984 annual depletion of North Sea Oil equalled about 20 billion 1990 pounds. Table

4 also shows the impact of the large fall in the price of oil in 1986 on measured growth in 1985/6. According to the NNP_t^{HS} formula, Britain experienced a huge fall in NNP. In contrast, according to the $E_{t+1}NNP_t$ and $E_{96}NNP_t$ formulae, NNP actually rose faster during this period than GNP. This is because, once the price of oil collapsed, North Sea Oil revenue and depletion did likewise. Therefore, the gap between GNP and NNP was reduced, i.e., NNP grew faster than GNP.

Insert Table 4 Here

5. The Depletion of Oil and its Impact on Indonesian NDP

We conclude by comparing the Net Domestic Product (NDP) series obtained by Repetto et al. (1989) for Indonesia between 1971 and 1984 with the NDP series obtained using the depletion formulae $E_{t+1}D_t$ and $E_{85}D_t$ defined in (28). Repetto et al. consider the impact of depletion of petroleum, forestry, and soil on the sustainability of growth in Indonesia. Here, however, we will focus just on the depletion of petroleum. Repetto et al. compute petroleum depletion using the Haig-Simons formula, D_t^{HS} , defined in (30). The GDP_t and D_t^{HS} series shown in Table 5 are obtained from Repetto et al.'s Table I.2. The petroleum rents, R_t , are taken from Table II.4. The R_t data in Table II.4 are in current millions of US dollars. To obtain the R_t series in Table 5, it was first necessary to convert the data into Indonesian rupiah, and then convert them into 1973 rupiah using the Indonesian GDP deflator. The $E_{t+1}D_t$ and $E_{85}D_t$ series are derived directly from the R_t data using equation (54) with ($r = 0.05, \alpha = 0.95$). All three NDP series in Table 5 are obtained by subtracting their respective depletion data from GDP. NDP_t^{HS} denotes the NDP series, adjusted for depletion of petroleum only, generated by Repetto et al.

Insert Table 5 Here

Insert Figure 3 Here

GDP and the three NDP series are graphed in Figure 3. The most striking feature of Figure 3 is the huge spike in the NDP_t^{HS} series in 1974. Repetto et al. attribute

this to changes in the US tax law and Indonesian contracts favorable to exploration activities, which led to a sharp increase in reported reserves. Irrespective of its precise cause, the spike has little if any bearing on the sustainability of growth in Indonesia. In contrast, the NDP series, $E_{85}NDP_t$, actually falls slightly in 1974, while $E_{t+1}NDP_t$ rises only slightly. The $E_{t+1}NDP_t$ and $E_{t+1}NDP_t$ series provide more useful guides to the sustainability of the Indonesian economy than NDP_t^{HS} . The years 1971-3 were characterized by negative depletion, as oil production started to increase from an initially lower level. After 1979, however, Indonesia has experienced depletion in the order of 1000 billion rupiah each year. The average growth rate of NDP also differs significantly depending on which formula is used. The average annual growth rate of $E_{85}NDP_t$ is 5.30%, compared with 3.99% for NDP_t^{HS} , 6.67% for $E_{t+1}NDP_t$ and 7.10% for GDP_t . These results, like Table 4, illustrate that there is no particular problem of bias in Haig-Simons income estimates over a reasonably long series of observations. The problem arises in the year to year comparisons which can be excessively volatile and seriously misleading with regard to sustainability.

6. Conclusion

The deficiencies of GNP as a measure of economic performance are widely recognized. NNP, if broadly defined to include depletion of the natural capital stock, provides potentially a much better yardstick by which to evaluate the performance of governments and countries. However, its use in practice has been severely undermined by its apparent volatility. It is shown here that the observed volatility in NNP is a direct consequence of the incorrect treatment of unexpected capital gains, which breaks the link between NNP and sustainability. When unexpected capital gains are handled correctly, NNP is no more volatile than GNP. Unfortunately, this requires the modelling of expected future receipts from natural assets such as oil fields. This creates its own problems. The empirical estimates of NNP for Great Britain and Indonesia are obtained assuming a geometric path for future receipts. Although these results are only illustrative, they clearly

demonstrate the importance of the treatment of unexpected capital gains. It is hoped that these findings will encourage governments, national statistical offices, international organizations and journalists to pay more attention to environmentally-adjusted NNP as a useful tool for evaluating the performance of countries over time.

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Table 1.— North Sea Oil Data

Year	q_t^O	p_t^O	TR_t^O	q_t^G	p_t^G	TR_t^G	TR_t	TC_t	R_t	I_t	K_t
1975	0.9	135.8	121	36.3	19.6	710	834	256	578	6810	7308
1976	11.6	170.6	1985	38.4	21.3	820	2939	414	2526	7024	13680
1977	37.4	163.8	6128	40.3	21.9	884	7149	577	6572	6401	19883
1978	52.9	131.3	6947	38.5	28.1	1083	8148	867	7281	5711	25091
1979	76.6	161.3	12352	39.2	30.0	1179	13742	1136	12606	5124	29297
1980	78.9	202.4	15976	37.3	31.8	1186	17555	1330	16225	5182	32663
1981	88.0	228.5	20095	37.4	37.1	1388	21893	1750	20143	5708	35885
1982	100.3	215.2	21589	37.8	38.6	1462	23856	2002	21854	5998	39440
1983	111.0	216.2	23995	38.7	41.8	1618	26663	2173	24491	5584	43072
1984	121.3	228.1	27674	38.5	46.9	1805	30749	2408	28340	6272	46071
1985	122.5	204.5	25046	43.0	52.2	2244	28694	2953	25741	5660	49578
1986	121.3	93.3	11310	45.3	54.0	2446	14823	2721	12102	4373	52263
1987	117.7	97.7	11495	47.6	50.5	2405	14976	2546	12430	3461	53501
1988	109.5	73.0	7989	45.8	51.2	2345	11169	2350	8818	3800	53751
1989	87.4	86.9	7592	44.8	50.5	2261	10568	2479	8088	4152	54326
1990	88.0	94.2	8291	49.6	47.6	2360	11326	2847	8479	5082	55218
1991	86.8	81.8	7107	55.2	50.8	2802	10716	3145	7571	6622	56987
1992	89.2	74.7	6664	56.0	48.4	2705	10273	3018	7255	6297	60190
1993	94.0	75.0	7048	65.3	47.5	3101	11209	3222	7987	5126	62875
1994	119.0	64.4	7664	69.6	47.1	3280	12229	3347	8881	3958	64229
1995	121.8	67.7	8250	75.5	45.8	3457	13192	3298	9894	4554	64333
1996	121.8	78.9	9607	89.9	47.8	4293	15514	3250	12264	4430	65027

**Table 2.— Depreciation, Depletion, NNP and GNP in Millions of 1990
Pounds ($r = 0.05, \alpha = 1$)**

Year	δK_t	D_t^{HS}	$E_{t+1}D_t$	$E_{96}D_t$	NNP_t^{HS}	$E_{t+1}NNP_t$	$E_{96}NNP_t$	GNP_t
1976	821	-38951	0	-9352	439228	400277	409630	401098
1977	1193	-80918	0	-5774	486200	405282	411056	406475
1978	1505	-14185	0	-5354	434555	420370	425723	421875
1979	1758	-106494	0	-297	539011	432516	432813	434274
1980	1960	-72390	0	3308	492619	420228	416920	422188
1981	2153	-78353	0	7391	495383	417030	409639	419183
1982	2366	-34220	0	9472	458439	424219	414747	426585
1983	2584	-52738	0	12582	494194	441456	428873	444040
1984	2764	-76994	0	17061	530210	453216	436155	455980
1985	2975	51996	0	15314	415005	467001	451687	469976
1986	3136	272775	0	2441	217390	490165	487724	493301
1987	3210	-6565	0	2892	519260	512695	509803	515905
1988	3225	72236	0	-576	466783	539019	539595	542244
1989	3260	14602	0	-1334	534699	549300	550635	552560
1990	3313	-7815	0	-1010	556889	549074	550084	552387
1991	3419	18163	0	-1969	518876	537039	539008	540458
1992	3611	6324	0	-2384	530628	536953	539336	540564
1993	3773	-14646	0	-1771	561880	547234	549005	551007
1994	3854	-17884	0	-965	594964	577080	578045	580934
1995	3860	-20265	0	0	610916	590651	590651	594511

Table 3.– Depreciation, Depletion, NNP and GNP in Millions of 1990
Pounds ($r = 0.05, \alpha = 0.95$)

Year	δK_t	D_t^{HS}	$E_{t+1}D_t$	$E_{96}D_t$	NNP_t^{HS}	$E_{t+1}NNP_t$	$E_{96}NNP_t$	GNP_t
1976	821	-18502	1263	-7395	418779	399014	407672	401098
1977	1193	-38436	3286	-3719	443718	401996	409001	406475
1978	1505	-6738	3640	-3195	427107	416729	423565	421875
1979	1758	-50585	6303	1970	483101	426213	430546	434274
1980	1960	-34385	8113	5688	454614	412116	414540	422188
1981	2153	-37218	10071	9890	454248	406958	407140	419183
1982	2366	-16255	10927	12095	440473	413292	412123	426585
1983	2584	-25051	12245	15337	466506	429210	426119	444040
1984	2764	-36572	14170	19954	489788	439046	433262	455980
1985	2975	24698	12870	18352	442303	454131	448650	469976
1986	3136	129568	6051	5630	360597	484114	484535	493301
1987	3210	-3118	6215	6240	515813	506480	506455	515905
1988	3225	34312	4409	2940	504707	534610	536079	542244
1989	3260	6936	4044	2357	542365	545256	546943	552560
1990	3313	-3712	4240	2866	552786	544834	546208	552387
1991	3419	8627	3785	2101	528411	533253	534938	540458
1992	3611	3004	3627	1890	533949	533325	535063	540564
1993	3773	-6957	3993	2717	554191	543241	544518	551007
1994	3854	-8495	4441	3747	585575	572640	573334	580934
1995	3860	-9626	4947	4947	600277	585704	585704	594511

Table 4.— Average Annual Real Growth Rates of NNP and GNP

	1976/95	1976/95	1985/86	1985/86
	$r = 0.05$	$r = 0.05$	$r = 0.05$	$r = 0.05$
	$\alpha = 1$	$\alpha = 0.95$	$\alpha = 1$	$\alpha = 0.95$
$g(GNP_t)$	2.093	2.093	4.963	4.963
$g(NNP_t^{HS})$	1.752	1.913	-47.618	-18.473
$g(E_{t+1}NNP_t)$	2.069	2.041	4.960	6.602
$g(E_{96}NNP_t)$	1.945	1.925	7.978	7.998

Table 5.— Depletion, NDP and GDP in Billions of 1973 Rupiah Between 1971 and 1984 ($E_{85}NDP_t$ calculated assuming $r = 0.05, \alpha = 0.95$)

	R_t	D_t^{HS}	$E_{t+1}D_t$	$E_{85}D_t$	NDP_t^{HS}	$E_{t+1}NDP_t$	$E_{85}NDP_t$	GDP_t
1971	274	-1527	137	-854	7072	5408	6399	5545
1972	476	-337	238	-694	6404	5829	6761	6067
1973	595	-407	298	-610	7160	6456	7363	6753
1974	1281	-3228	641	46	10524	6656	7250	7296
1975	1224	787	612	-10	6844	7019	7641	7631
1976	1271	187	636	37	7969	7521	8119	8156
1977	1446	1225	723	214	7657	8159	8668	8882
1978	1344	1117	672	123	8450	8895	9444	9567
1979	1381	1200	691	166	8965	9475	9999	10165
1980	2161	1633	1081	955	9536	10089	10214	11169
1981	2505	1552	1253	1347	10503	10803	10708	12055
1982	1796	1158	898	705	11167	11427	11620	12325
1983	2113	1825	1057	1057	11017	11786	11785	12842
1984	2007	1765	1003	1003	11755	12517	12517	13520

Figure 1: GNP and NNP for Great Britain ($r=0.05$, $\alpha=1$)

Figure 2: GNP and NNP for Great Britain ($r=0.05$, $\alpha=0.95$)

Figure 3: GDP and NDP for Indonesia ($r=0.95$, $\alpha=0.95$)