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Resource Accounting, Sustainable Development and Well-Being

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The Author has since the late 80's now and then been committed to the research that will be reported in this paper. In fact, he published some of the conclusions already in 1974. However, the present paper is not really his own. Much of the conclusions are based on joint research with Partha Dasgupta, Cambridge University and Bengt Kriström, Umeå University. As they have not seen this paper, they are excused for all misprints etc. However, they share the credits and the blame for the intellectual content.

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Le opinioni espresse nel presente lavoro non rappresentano necessariamente
la posizione della Fondazione Eni Enrico Mattei

SUMMARY

There are now quite many publications on the construction of an environmentally adjusted net-national product measure. Most of these publications base the discussion on rather ad hoc constructions of the national accounts. In this paper, I try to develop an accounting framework from basic economic principles and relate this framework to the notion of sustainable development. I then review a few empirical studies in view of the findings of this paper. In an appendix, the discussion in the main text is supported by mathematical analysis.

NON TECHNICAL SUMMARY

It is self-evident that all economies depend on their natural resources, such as soil and its cover, water, forests, and animals, and that a misleading picture of productive activity in the economy is obtained when the environmental-resource bias is ignored. However, until very recently, i.e. the publication of the Brundtland Report in 1987, development economics neglected environmental resources in government planning models.

Today, no account of economic development - in poor countries or in rich countries - would be regarded as adequate if the environmental resource-base were absent from it.

This paper explores the consequences of basing resource accounting on firm theoretical grounds, showing that an accounting system can be constructed using conventional tools of welfare economics, i.e. it develops an accounting framework from basic economic principles and relates it to the notion of sustainable development.

The paper starts with a brief discussion of ecological systems, including their functions and services, and how to extend the existing accounting system to accommodate such functions and services.

It then reviews a number of existing and proposed applications to see how they relate to this extended framework.

Japan was one of the first countries to adjust the national product in a welfare-oriented way. The Statistical Bureau of the Netherlands is particularly active in promoting "green GDP" calculations. Denmark and Sweden have recently completed two studies reaching widely different conclusions, while work is currently under way in a number of countries, in particular Australia, Canada and Germany. The Bureau of Economic Analysis in the United States is also developing a "green GDP".

Detailed sections are devoted to resource accounting in Indonesia, Malaysia, Sweden and Columbia, and to an intuitive discussion on the System of integrated Environmental & Economic Accounting (SEEA) developed by the UNSTAT (Statistical Division of the United Nations) with analyses of integrated economic and environmental accounting systems for Mexico and Papua New Guinea.

In the appendix, the discussion in the main text is supported by mathematical analysis.

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RESOURCE ACCOUNTING, SUSTAINABLE DEVELOPMENT AND WELL-BEING

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Abstract

There are now quite many publications on the construction of an environmentally adjusted net-national product measure. Most of these publications base the discussion on rather ad hoc constructions of the national accounts. In this paper, I try to develop an accounting framework from basic economic principles and relate this framework to the notion of sustainable development. I then review a few empirical studies in view of the findings of this paper. In an appendix, the discussion in the main text is supported by mathematical analysis.

1. The resource-basis

That all economies depend on their natural resources, such as soil and its cover, water, forests, animals, and fisheries should be self-evident: ignore the environmental-resource base, and we are bound to obtain a misleading picture of productive activity in the economy. Nevertheless, in most economic analyses, there has been a neglect of the resource base, and in particular in analysis of economic development in poor countries. These countries rely heavily on their environmental- and natural resource base. Until very recently, environmental resources made but perfunctory appearances in government planning models, and they were cheerfully ignored in most of what goes by the name development economics.

The situation is now different. As regards timing, the shift in attitude can probably be identified with the publication the Brundtland Report - Our common future - 1987, and today no account of economic development - in poor countries or in rich countries - would be regarded as adequate if the environmental resource-base were absent from it.

What I will try do to in these lectures is to discuss with you how one could design a framework to incorporate environmental- and natural resources into the national income accounting framework. I will start with a brief discussion of ecological systems and their functions and services and then go on

¹I have since late 80's now and then been committed to the research that will be reported in this paper. In fact, I published some of the conclusions already in 1974. However, the present paper is not really my own. Much of the conclusions are based on joint research with Partha Dasgupta, Cambridge University and Bengt Kriström, Umeå University. As they have not seen this paper, they are excused for all misprints etc. However, they share the credits and the blame for the intellectual content.

to a more intuitive discussion of an appropriate framework for extending the existing accounting system to accommodate these functions and services. After that, I will review a number of applied studies and in particular see how they relate to this extended framework. Tomorrow I will go into more technical discussions of the theory behind the framework. Most of what I am going to present today will be based on joint work with professor Partha Dasgupta, Cambridge University, and with professor Bengt Kriström, The Swedish Agricultural University.

2. Eco-systems: Functions and services

The ecological services we rely upon are produced by ecological systems or eco-systems for short. These services are generated by interactions among organisms, populations of organisms, communities of populations, and the physical and chemical environment in which they reside. Eco-systems are involved in a number of functions and offer a wide range of services. Many are indispensable, as they provide the underpinning for all human-activities. So they are of fundamental value. Among other things, eco-systems are the sources of water, of animal and plant food and other renewable resources. They also maintain a genetic library, sustain the processes that preserve and regenerate soil, recycle nutrients, control floods, filter pollutants, assimilate waste, pollinate crops, operate the hydrological cycle, and maintain the gaseous composition of the atmosphere. The totality of all the eco-systems of the world represents a large part of what we may call our natural capital-base. The natural capital-base also includes in addition minerals, ores and other exhaustible resources. However, for the moment let me focus on the renewable resource-base. For vividness, I will often refer to it as the environmental resource-base. Environmental problems are thus almost always associated with resources that are regenerative, but that are in danger of exhaustion from excessive use. For this reason we may identify environmental resources with renewable natural resources.

Environmental economists find it very often useful to base their studies on ecosystem ecology. Here the focus is on such objects as energy at different trophic levels and its rate of flow among them, the distribution and flows of bio-chemical substances in soils and bodies of water, and of gases and particulates in the atmosphere. The motivation here is to study the biotic and abiotic processes underlying the various functions that are performed by ecosystems. Holling's characterization of ecological processes as one of cycles of birth, growth, death, and renewal, is a particularly illuminating example of this viewpoint. In such settings, the central concern of the economist, is the valuation of the services that are provided by ecosystems, studies of efficient management plans and analysis of the appropriate institutional setup for implementing these plans.

Since the services the environmental resource base provides us are essential for our survival, it would seem prudent to monitor it in much the way we routinely monitor our manufactured capital stocks, such as roads, buildings, and machinery. Unhappily, this has not been standard practice. It is even today not conducted in any systematic way. Instead, reliance is often placed on time trends in gross outputs of commodities, for example agricultural crops, and trends in their prices for obtaining a sense of, for example, whether growth in the world's population has been imposing strains on the environmental resource base. This is a mistake. Agricultural output could in principle display a rising trend even while the soils are being mined. Increasing production is consistent with unsustainable production. Growing and sustainable output are not the same and it is a fundamental error to think that they are so.

There is therefore a substantial need for the construction of systems of monitoring our use of environmental and non-renewable resources. In economics, the most important monitoring system we have is the system of national accounts. It therefore seems to be worthwhile to try to extend these accounts to include the flow of environmental services and changes in the stocks of the resource-base.

3. Introduction to national accounts

The systematic compilation of economic data into national accounts ranks among the most important innovations in the social sciences. With roots in Quesnay's tables and William Petty's 17th century assessments of England's national income, the current system of national accounts (SNA) integrates a wealth of information pertaining to the economic state of a nation. Its importance in today's economic life cannot be overestimated. The SNA remains the basis for the construction, evaluation, and comparison of economic performance throughout the world. At a more mundane level, the information presented in the SNA belongs to everyday economic drama. Witness, for example, the flurry of activities triggered by the publication of the quarterly U.S. figures on Gross Domestic Product (GDP) or, say, the Japanese current account figures.

Traditionally, the purpose of the SNA has been closely related to analyses of an economy's productive capacity. When James Meade & Richard Stone developed the first versions of the SNA in the early years of World War II they attempted to shed light on the extent to which Great Britain's resources could be allocated to fighting the war. Generally, the development of the SNA and other similar systems have been triggered by the particular resource allocation problems of the day. With the emergence of "environmental problems", it is only natural that the scope of the SNA is scrutinized.

While the SNA contains a rich source of information about an economy, it is fair to say

that the gross national product - GNP - is the most important concept in the system. First, GNP is often used as an index of welfare in a country. If GNP increases, then this is taken as a sign that the average welfare in the country increases. Second, if GNP in one country is greater than GNP in another, then the first country is thought to have a higher welfare. Indeed, the notion of GNP as a measure of "material" well-being is deeply rooted in the minds of generations of economists, journalists, politicians and other participants in the public debate.

My presentation has two purposes. The first is to discuss the theoretical basis for using a national product concept as an index of well-being, as well as to show how a proper environmentally adjusted national product should be calculated. I stress at the outset that national income accounts serve other purposes, they do not merely measure well-being. In particular, it may be of substantial importance to include environmental resources into national accounts in order to establish a database that could be used for modelling purposes. It seems to be an increasing demand for quantitative analyses of the connection between macroeconomic performance and the environment, not the least in connection with global warming. Therefore, big efforts are being invested in the establishment of extended national accounts including flows of pollutants, harvest of environmental resources, production of exhaustible resources, etc. In spite of the importance of these developments, I will not touch upon them further.

I will focus on the "green national product" and in particular how it should be based on a conceptual basis that permits a welfare-theoretic interpretation of the measure. This is a point that I will return to several times in this chapter. The second purpose is to review some of the major empirical studies on resource accounting.

Before going into the discussion of the theoretical basis for the construction of the NNP index, it may be as well to present some of the issues that are being debated in this connection:

- The treatment of labour
- The inclusion of human capital
- The inclusion of environmental damages
- The treatment of "defensive" expenditures
- The calculation of depreciation charges on stocks of environmental and natural resources

4. The National Product as a Welfare measure

Provided certain technical restrictions are met, which I will return to, for any conception of social

well-being, and for any set of technological, transaction, information, and ecological constraints, there exists a set of shadow (or accounting) prices of goods and services that can be used in the estimation of real net national product (NNP). The index in question has the following property: small investment projects that improve the index are at once those that increase social well-being. We may state the matter more generally: provided the set of accounting prices is unaffected, an improvement in the index owing to an alteration in economic activities reflects an increase in social well-being. This is the sense in which real net national product measures social well-being.

Moreover, the sense persists no matter what is the basis upon which social well-being is founded.²

The emphasis on small projects is deliberate: NNP is a linear index. If the alterations in economic activities were not small (i.e. if they were to affect the accounting prices), the appropriate index of social well-being would be non-linear. This is because the index would then have to include changes in consumers' and producers' surpluses, and changes in income distributional weights.

Notice that, in this reckoning, NNP should be thought of as the criterion function on the basis of which social cost-benefit analyses of economic policies ought to be conducted. However, depending upon the basis on which accounting prices are estimated, it could be computed in a number of ways. One possibility (the one we explore in detail in this chapter) would be to use prices that sustain an optimal plan. An alternative would be to use "local prices" (e.g. the prices households actually face when they make consumption decisions). A third possibility would be to rely on local prices for the current period and optimal prices for future periods. And so on.

In order to illustrate these ideas, consider an economy consisting of two consumer goods and a single individual. In Figure 1 X and Y denote the two goods and the curve TT' denotes the production possibility frontier. Let $W(X, Y)$ be the individual's well-being function and Π' the indifference curve which is tangential to TT' (tangency is at the point A). In the figure we have assumed that the production possibility set is convex and that $W(X, Y)$ is a concave function. The common tangent at A , which we have denoted as pp' , defines the optimal prices, p_x and p_y . We may then define NNP at any production point, (X, Y) , as $p_x X + p_y Y$.

Let us assume that the economy is at C (a point on the production frontier). We wish to check if a move to B (also on the frontier), which is an improvement in the individual's well-being, records an increase in NNP defined as above. As Figure 1 shows, it does record an increase. Moreover, it can be confirmed that a move from C to any point on the frontier that records an improvement in NNP also reflects an improvement in the individual's well-being.

² It should be noted that national income accounts have other important uses; for example, as a tool for assessing the volume and composition of economic activities.

Thus far we have illustrated the use of optimal prices for measuring NNP. For points inside the production possibility set, these prices are inappropriate for the estimation of NNP. Instead, local prices ought to be used.³ The idea is simple enough. Let (X, Y) be the current consumption point. Then the individual's well-being is $W(X, Y)$. Consider now a small change in consumption (dX, dY) . Then, to a first approximation, the resulting change in the individual's well-being is $W_x dX + W_y dY$, where W_x and W_y are the two partial derivatives of W at (X, Y) . The change is desirable if $W_x dX + W_y dY > 0$; it is undesirable if $W_x dX + W_y dY < 0$. This means that W_x and W_y could be used as the accounting prices. In other words, NNP, evaluated on the basis of current marginal valuations, is an appropriate measure of social well-being.

Now it can be shown that an indefinite sequence of improvements of this kind (where the improvement at each stage is measured at the prevailing marginal valuations) would eventually lead to the optimal consumption point, A (Arrow and Hurwicz, 1958). This is called the gradient process.

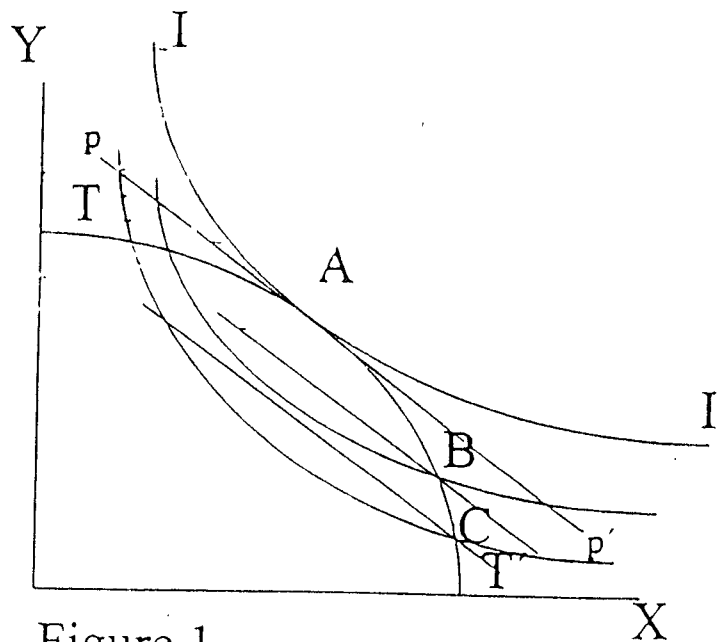


Figure 1

³ Of course, local prices could be used also for points on the frontier.

The simple ideas expounded above will now be used to develop a framework for the construction of an index for a more complicated economy. The restriction to two commodities is in fact more general than we need. Thus we will in fact limit ourselves to one consumer good, without restricting the generality of the analysis. Maintaining the assumption of only one individual also allows us to bypass distributional issues.

I will tomorrow give a brief outline on how to use local prices, that is prices that do not necessarily correspond to an optimum. Such an approach would be more consistent with current accounting practices and would also make life much easier for those who are going to implement the accounting framework.

5. Issues in the construction of a green national product

We use an optimal growth model to study the most important characteristics of an accounting framework. This approach has many advantages, one being that it provides insights into the nature of the shadow prices we need. The analysis depends heavily on Mälér (1991), Dasgupta & Mälér (1991) and Dasgupta, Kriström & Mälér (1995). Details of the analysis will be presented tomorrow.

5.1 Labour

Imagine two countries, both with perfectly competitive markets, that differs only in the number of hours worked. If leisure-time is valued positively, should our welfare indicator record any difference between the countries?⁴ Given that the two countries' national products are equal, the conventionally computed GNP suggests that welfare in both countries is also equal. Thus under the current accounting systems the answer would be no. In this section we show how such conclusions would be modified, if the purpose were to obtain a welfare indicator.

We assume, for the time being, that there is only one factor of production - labour. We also assume that there is a perfect market for labour that is in equilibrium at each point of time. If the supply of labour were completely inelastic we need not consider the issue of labor further. The individual works a given amount of time and there is no leisure-labor choice. Instead assume that the labor supply is elastic. At the margin, the individual is indifferent between working one more hour or having one more hour for leisure. This being the case, and given the fact that we are only trying to evaluate marginal projects, wage income should not be part of our index. This may not be obvious,

⁴ The link between the national product as a welfare measure and the treatment of labour goes back at least to Pigou.

but the following example may clarify our point.

Consider a constant returns to scale project which increases labour hours worked, at the expense of reduced leisure time. Such a project has no effect on well-being. This is because the gains from increased production of consumer goods are completely offset by the opportunity cost of lost leisure-time. *Thus, with perfect, equilibrating labour markets, labour income should not be included in the national product measure.*

This is a rather startling conclusion in view of the historical fact that national income measures were originally constructed as an aid in designing demand-side economic policies. Obviously then, the national product has at least two different uses. The appropriate concept for one purpose is typically different from that which is appropriate for another. It is, in fact, necessary to distinguish between different concepts of national products. Preferrably, we should give the different concepts different names. In spite of this we will in this chapter continue to use national product as the generic name for our index for evaluating marginal projects.

Our conclusion above is based on a number of implicit assumptions. The most questionable is that labour markets equilibrate. I will return to this assumption tomorrow. Though obviously this condition does not always hold, we can still construct an index, proceeding as if the labor markets are in equilibrium. Alternatively, we can use the local prices, i.e. the workers marginal reservation price for taking a job. Assume for simplicity that the reservation price is zero, i.e. the worker is willing to take a job as long as he gets something above zero. The accounting price for labour is then zero and the wage bill, evaluated at this price, would also be zero.⁵

This discussion has important implications for the discussion on how to treat "defensive expenditures". Such expenditures are dedicated to cleaning up damaged environments.⁶ It has been suggested that conventional national income accounts would register an increase in GNP because of damage to the environment due to pollution. The reason is that companies (or the public sector) will hire labour to clean up the environment. This will show up as an increase in GNP. Therefore, it is argued, defensive expenditures should be deducted from GNP. This conclusion is clearly not correct. If the economy is in full employment, then hiring of people in the clean-up industry will be offset by a reduction in production somewhere else in the economy. If the economy is not in full employment, then (assuming we are using the local prices) the wage bill should be zero, and there will be no increase in GNP.

I have assumed that labour time and leisure are substitutes. This assumption needs to be modified

⁵ We have explored the consequences of labor market disequilibrium in detail elsewhere.

⁶ See also section 3.2. for more on defensive expenditures.

when workers carry human capital. Part of their salaries is a return on that capital and cannot be regarded as a substitute for leisure. Only the part of their salaries that correspond to "raw" labour, on the margin, will be valued at the same rate as leisure. The return on human capital should therefore be included in our index. This may create severe practical problems, because there does not exist any reasonable empirical approach to separate returns on human capital from the "return" to raw labour.

5.2 Flows of goods and services

Human welfare depends on many non-market goods and services. A few of these are already included in the SNA. For example, production in the public sector is in general not marketed but included in GNP. Needless to say, many important goods and services are neglected in the current SNA. In fact, human life depends crucially on services provided by fundamental ecological systems. Inclusion of these services changes the national accounts in two ways. First, it changes the current flow of goods and services. Secondly, it changes the future flows via current changes in the resource base.

The current flow of services from natural capital affects human well-being in at least two ways. First, the flow can directly affect human well-being, as exemplified by clean air, recreational opportunities and food gathering. It can also affect human well-being indirectly when the services are used as inputs in production. If the relevant production units are included in the national accounts, then changes in the flow of current services are measured by the conventional GNP; a change in the quantity of one service will affect the operating surplus and the operating surplus is accounted for in the value added of the production unit. This means that indirect uses will already be reflected in the current SNA, if the relevant production units are included.

The direct use of ecological services is not accounted for in SNA. There is a considerable confusion in the literature as how to include the direct services in an adjusted national product. The confusion arises largely from problems of definition. One example illustrates this point. Assume that an individual is disturbed by noise from a nearby highway. An increase of the traffic-volume will raise the noise level and reduce the well-being of the individual. In response, the individual might invest in three-pane windows and increased insulation. Should these defensive expenditures be subtracted in order to obtain a more appropriate national product index? In other words, are the expenditures reasonable money measures of the utility loss?

The answer to these questions lies in the way we are measuring the environmental damage. Let N be the outdoor noiselevel. As a result of the increased traffic, the noise level increases from N^0 to N^1 . Let the original indoor noiselevel be M^0 and assume that the level is maintained through defensive expenditures. Let $D(N)$ be the damage function (the willingness to pay for a quiet neighborhood).

One correct way of adjusting the national product index is to subtract

$$D'(N^0) * (N^1 - N^0) = D(N^1) - D(N^0)$$

from the conventional national product. Because we are studying a marginal change, $D'(N)$, we use the marginal damage function. Note that this implies that we are using local prices, i.e. the marginal willingness to pay for noise reduction in the actual situation (where noise is N^0). In this case, we should ensure that all prices used in computing the index are reflecting the actual marginal willingness to pay for the goods and services. We could also have made use of the optimal prices. If N^* is the optimal noise level, then the adjustment would have been $D'(N^*)(N^1 - N^0)$.

Sometimes a different formulation is used, where the damage function is $D(M)$. Because of the defensive expenditures, the indoor noise level is unchanged. Thus, the national product should therefore be subtracted by these expenditures. This is correct, *if the defensive expenditures are approximately equal to $D'(N^0) * (N^1 - N^0)$.*

It is important to remember that there is no reason to assume that defensive expenditures are a good approximation of the true environmental damage. In fact, one can imagine cases where environmental damages is negatively correlated with the defensive expenditures. It may therefore be dangerous to use defensive expenditures uncritically as a measure of the environmental damage.

5.3 Valuation issues

During the last twenty years or so, the techniques for estimating environmental damages in monetary terms have been extensively developed.⁷ These techniques have been developed for use in particular situations where a cost-benefit analysis is needed for making a specific decision, and not for use in the production of national product estimates. If these rather sophisticated techniques were to be used, the cost for adjusting the national product measures would likely be prohibitive. Therefore, more simple, but still robust methods are needed.

The conventional way of including the public sector in SNA may give some clues as to how to find reasonably accurate and inexpensive valuation methods. Because the output from the public sector is, in general, not marketed there is no way of assessing the value of that output directly. SNA has solved the problem by looking at the cost of production in the public sector (mainly labour cost). This is a correct approach if the public output corresponds to the demand. In fact, if politicians are able to make correct decisions on the size and composition of the public sector, then the cost of production (including cost of capital) in the public sector would exactly correspond to the value of

⁷ See f.e. Freeman (1993) and the chapters by Mitchell & Carson, Hanemann & Kriström and Harrison & Kriström in this book.

the output. Thus one possibility would be to use the same basic idea when approximating the value of environmental damage.

The use of a 'politically determined' willingness to pay would require that there are politically determined targets for environmental policies - ambient standards, emissions targets etc. The situation is illustrated in Figure 2. Here MC is the marginal cost of abating emissions and MD is the marginal damage from the emissions. The total abatement and damage cost is minimized when marginal abatement cost equals marginal damage cost, i.e. at the point A.

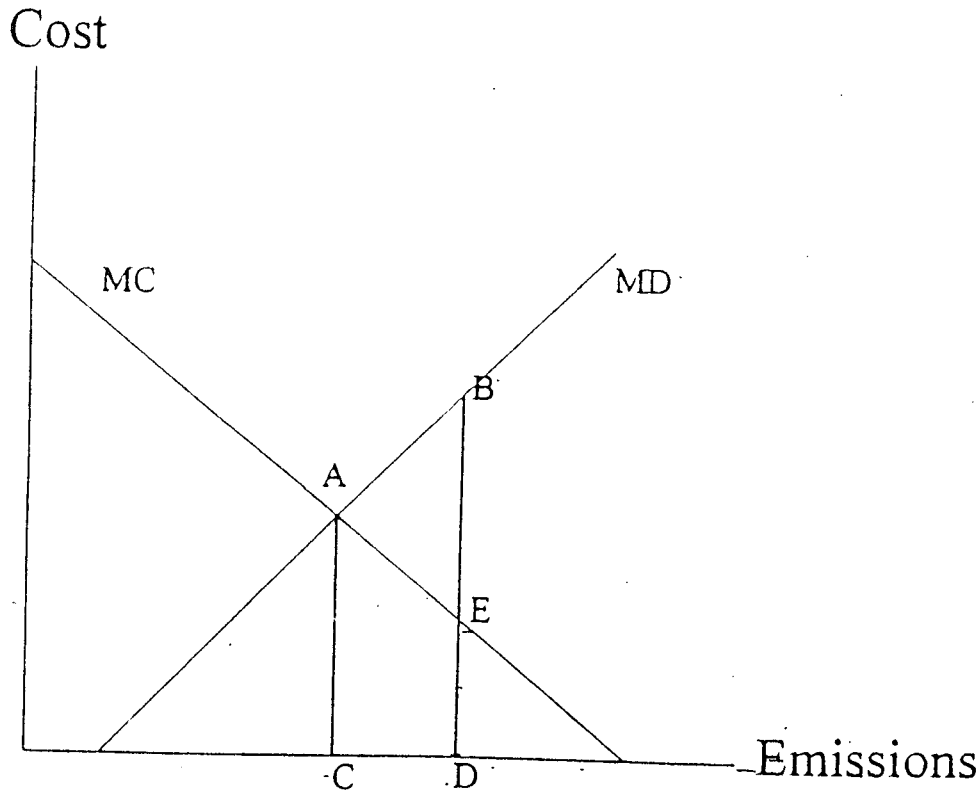


Figure 3

Assume that the current emissions are at D. It would then be desirable to reduce the emissions to C. The total cost of doing that is the area ACDE. The reduction in the environmental damages from such an emission reduction is ACDB. We immediately see that these two areas are correlated. An increase in this as well as the accounts. An increase in the environmental damages from an increase in the emissions will be accompanied by an increase in the abatement costs necessary to achieve the optimum level of pollution. Therefore, the cost of achieving the target emission reduction is, although hardly perfect, an approximation of the environmental damage. If the political system has determined explicit targets for environmental policies, then one could use the costs of achieving these targets as approximations when adjusting the conventional national product concepts for the flow of environmental services. However, politicians very seldom determine specific targets in environmental policies, and the scope of this approach to evaluating environmental damage is therefore limited.

Similarly, if the political bodies have determined emission taxes instead of quantity targets, these taxes could be interpreted as proxies for the social marginal damage from further pollution. In Sweden, the emission tax on sulphur is 30 000 SEK per tonne. This reveals implicitly that society

values the damage from one more ton as 30 000 SEK. Unfortunately, there are very few such emission taxes and in most countries there are no environmental taxes at all.

5.4 Transboundary pollution

The discussion has so far focussed on the situation in one country and has not included the interactions between a given country and the rest of the world. Obviously, modifying the analysis to consider such interactions involves accounting for transboundary pollution. Typical examples of transboundary pollution are upstream-downstream problems, where an upstream country effects a downstream neighboring country.

To construct a welfare index, and more generally a consistent accounting system, we need to return to the fundamental question; whose well-being should be considered? Should we consider the global population, or should we limit ourselves to the citizens of the own country? Either approach is equally valid, but they lead to different formulations of the indices as well as the accounts.

Begin by assuming that we are interested in a marginal cost-benefit rule for projects in one country. Then we should deduct the environmental damage "our projects" give rise to abroad. Thus, export of pollution should be counted negatively. Furthermore, as the cost-benefit rule applies to domestic projects only, the import of pollution should not be accounted for. If the objective is to create an index measuring the impact on global well-being from projects in one country, then environmentally damaging activities in other countries should not be included. If all countries based their accounts on this objective, all accounts would be consistent, and could thus be summed. In fact, the global national product calculated in this way would give the same result as the result from a calculation in which we would have considered the whole globe as one country.

Another way of doing the calculations would be to base them on a cost-benefit rule that considers all changes as the project, but limit the consequences to citizens in the home country. This is an equally valid starting point, though it will, in general, give a different answer. If all countries apply the same rule, we would once again have consistent system. The difference between the two approaches is similar to the difference between gross domestic product and gross national product, the difference being the treatment of factor payment across national borders.

The second issue in accounting for trade has to do with environmental assets. A good example is an oil-based country like Saudi-Arabia. If Saudi-Arabia is considered as an isolated island, it follows that NNP, properly measured, is zero. For a proof, see the appendix. Before we discuss this issue further, it will be helpful to discuss environmental assets in more detail.

5.5 Environmental assets

Some projects have effects on future welfare, through the accumulation and decumulation of productive assets. The well-being of future generations are reflected in the stock of assets the current generation is leaving to the future. If we are interested in the well-being of future generations, we should obviously include the net changes in the productive assets in the accounts.

In SNA (before 1993), changes in only two such assets are included - man-made capital and human capital. In the gross national product, GNP, gross investments in real capital are included. If we are interested in a welfare index that includes future generations, it is clear that the net national product, NNP, is a better index than GNP. What matters for future generations is the capital stock they inherit, and we should measure how much we add to this stock by focussing on net investments.

A particularly difficult stock of capital to measure in the context of NNP-measurement is human capital. Changes in the stock of human capital are consequences of education, research and development. Some of the costs for these activities are included in the standard GNP measure. They are typically classified as public expenditures. It seems reasonable to reclassify expenditures on human capital as investments. The largest cost for investments in human capital is neglected, however. This is the opportunity costs of the time students allocate to their studies. It seems reasonable that these costs should be part of the gross capital formation. On the other hand, it seems extremely difficult to define the depreciation charges needed for the calculation of the net change in the stock of human capital.

Changes in stocks of natural resources have typically not been included in SNA. As many of these resources generate essential life-supporting services, their exclusion may severely distort the net national product estimates. It should be of highest priority to try to include changes in the complete asset base in the accounts.

Exactly how changes in these assets should be included in the national accounts is still controversial, though it should not be. Once again, starting with the objective of creating a marginal social cost-benefit rule, we have to determine the impact current projects have on welfare. To do this it will be necessary to make some assumptions on what the future will look like. In deriving the appropriate accounting prices, the simplest and most practical assumption is to assume that the economy will follow an optimal path from now on; recall the discussion involving Figure 1. There we concluded that we could use the optimal prices even if the economy is not at the optimum. The same is true in a dynamic setting. We use the optimal path as a vehicle to compute accounting prices which are then used to value the current changes in resource stocks. Basically, these prices will reflect the present value of the future welfare stream from one more unit of the resource today. Having computed these accounting prices, it follows that we should add the value of changes of resource stocks at these prices to the conventional national product.

This conclusion has important implications. One implication is that we must include the price times the change in the resource stock. The change in the accounting price is not included. That is, we do not consider capital gains (or losses). Another implication involves exhaustible resources and the proper treatment of new discoveries. If discoveries are deterministic in that one can predict with some certainty that new reserves will be found, if investments are made in explorations, then the net stock may increase. On the other hand, if discoveries are completely random, then changes in the stock should be valued with accounting prices that take into account possible (but not certain) future discovery.⁸

Furthermore, the so called El Serafy⁹ model for computing the depreciation charges for exhaustible resources is incorrect, due to the fact that it is based on an arbitrary prediction of the future - a prediction which is not self-consistent. El Serafy considers the case when a resource has a fixed lifespan and generates a constant revenue for each of the remaining years. He then transforms this revenue to a consumption charge that can go on forever. This enables him to compute the depreciation charge. However, as the assumptions are arbitrary, the computed depreciation charge will also be arbitrary.

For many of the resources included in the stock of natural capital, the same valuation problems arise as did with the flow of services discussed in the previous section. There are no market prices for these assets because they are not subject to transactions. Instead, one has to follow the same rather ad-hoc approaches as were discussed. However, there are important resources for which there are market prices. Most of the exhaustible resources are traded on markets, and the established market prices could be used as a first approximation to compute the appropriate depreciation charges.

With the above details spelled out, we can now easily see how to properly handle capital flows. Consider a small open economy with a single asset, oil. As we explained above, without trading possibilities, the country has an NNP of zero. Assume now that the country can invest its proceeds in a resource elsewhere, which gives a rate of return equal to the world market interest rate. It then turns out, see the appendix, that we need to add the return on this additional stock to obtain a proper welfare measure. Again, the reason is intuitively clear. We have added an additional stock that may be used to provide for future generations. Additions to - or depletions - of this stock should be included in the welfare measure.

Let us try to summarize the findings so far. We are looking for a linear index that will show whether or not the performance of the economy during a specific time period has been improving the present

⁸ See Dasgupta & Mäler (1991).

⁹ El Serafy (1989).

value of current and future well-being. Such an index should look like the following:

*Net national product = consumption of marketed goods + public expenditures +
+ the value of the net change of real capital - wage bill for raw labour +
+ opportunity costs of time for students - flow of environmental damages +
+ the value of the net change in the environmental resource base.*

5.6 Sustainable development and sustainable income

It is possible to show that the net national product concept that was introduced in the previous section has some rather interesting properties:¹⁰

- i) If the optimum is approximately a steady-state, NNP will be the return on the total wealth in the economy, including real capital, human capital and natural capital
- ii) NNP will be the maximum constant wellbeing that, in the absence of non-anticipated technical progress, is feasible. A higher well-being today than NNP will reduce well-being in the future.

The NNP is a linear measure and if we are following an optimal path, it is a linear approximation of the optimal present value of future welfare. It can be shown that this optimal present value of future welfare will correspond to the return on the total wealth if the optimum is approximately a steady-state. NNP can thus be viewed, not only as an index for marginal cost benefit analysis but also as an index for whether the development is sustainable or not. A rigorous treatment of this is provided in the appendix.

6. An accounting system

The theoretical arguments put forward in the previous sections are obviously far different from the basic idea underlying the Standard National Accounts. Furthermore, they are also quite different from the ideas underlying System of Integrated Environmental and Economic Accounting (SEEA).¹¹ Obviously, the ideas expounded in this paper will be very difficult to implement, particularly because

¹⁰ See Mäler (1991) and Dasgupta & Mäler (1991).

¹¹ See below for a discussion of this system.

of the inherent difficulties of valuing environmental services.¹² However, it is possible to embed the arguments above in an accounting framework, similar to SNA. A brief presentation of such a framework is given in this section. The basic building block is a SAM - a Social Accounting Matrix - which can be used to summarize the accounting system in a compact way. The illustration below does not take into account the fact that wages for raw labour should not be included. It does not include international relations and it does not include the input/output structure of the economy. Furthermore, it would be much desirable to include a finer classification of institutions, including the public sector, instead of only have households as the only institutions.

¹² This is true for any application of resource accounting involving valuation of environmental damages.

Table 1. A Social Accounting Matrix (SAM)

	Households	Labour	Capital	Production	Abatement	Savings-Investment	Environment
Households		Wages	Profits				Rent
Labour				Wages	Wages		
Capital				Wages	Profits		
Production	Consumption				Inputs	Gross investment	
Abatement				Abatement			
Savings-Investment	Household savings			Depreciation	Depreciation		
Environment	Environmental services			Environmental damages	Environmental damages	Value of the net change of resources	

The economy has been divided into seven different accounts: households, two factors of production, one for production, one for abatement (or for expenditures for environmental improvements in general), capital/savings account and one for the environment. Each row corresponds to incomings for the corresponding account, while the columns correspond to the outgoings. The households' incomes is the sum of wages, profits and an implicit rent on the environmental assets. These incomes are spent on purchases of consumer goods, savings (including savings in the form of net additions to the environmental assets), and the imputed value of the environmental services consumed by the households. In a corresponding way, the ingoings to the production account are the incomes from sales to household, the sales to firms for investment goods and from the sales to the account for abatement. The total gross savings in the economy consists of household savings and depreciation of capital stocks. This savings corresponds to investment in real capital and net additions to the stock of natural capital.

The net national product is given as the sum in the first column, i.e. the value of consumption plus net savings less the reduction in environmental services, i.e. environmental damages. The net national income is given in the usual way as the sum in the first row, i.e. wages plus profits plus the return on

environmental capital.

7. Survey of applications

In this section we survey a number of existing and proposed applications of resource accounting. Given the pace of development in this area, it is difficult to compile an exhaustive survey. The interested reader is encouraged to consult the original sources for details.

Japan was one of the first countries to adjust the national product in a welfare-oriented way. Uno, in 1973, followed Nordhaus & Tobin (1972), proposed a measure of economic welfare by adjusting the national product in a number of ways.¹³ The most interesting adjustment, in this context, was the way environmental damages was monetized. Uno suggested that the damages could be approximated by the cost for reaching an environmental goal. Thus, if the officially stated goal is to reduce sulphur-emissions by 30%, then one can approximate current sulphur-damages by the cost of reaching this goal. Uno's suggestion is interesting and theoretically quite appealing, as we discussed above.

The Statistical Bureau of the Netherlands is particularly active in promoting "green GDP" calculations. In the beginning of the seventies, the bureau made several attempts to correct the national income by taking into account environmental damages. The work has continued in the 1990's, see Hueting (1990) for an overview.

Denmark and Sweden have recently completed two studies on resource accounting, each reaching widely different conclusions (see Danish Bureau of Statistics (1990) and SOU (1991:37)). The Danish position is strongly negative towards monetary accounts, while the Swedish commission expressed cautious optimism. Currently, a number of Swedish governmental bodies are involved in developing resource accounting systems. The Swedish National Institute of Economic Research is responsible for developing monetary accounts, while Statistics Sweden (SCB) pursues the work on physical accounts. Also, the Swedish Environmental Protection Agency is involved in these efforts and is currently compiling 'environmental indices'.

Work is currently under way in a number of other countries. In particular, Australia, Canada and Germany are active. Several international organizations, such as the OECD, the World Bank and the United Nations are actively supporting the development of resource accounting systems. A particularly significant publication is the recently published Handbook of Integrated Environmental and Economic accounts by the UN statistical office. Finally, I would like to note that the president of

¹³ See Economic Council of Japan (1974) "Measuring Net National Welfare for Japan", Tokyo.

the United States has instructed the Bureau of Economic Analysis to develop a "green GDP".¹⁴ Such work is now undertaken both in Congress and in government. Unfortunately, I am not that familiar with that work and I will therefore not comment upon it.

7.1 Indonesia

The study of Indonesia by Repetto and his co-workers (1989) is perhaps the best-known application of resource accounting. Central to this work is the observation that in the SNA (before -93) depreciation of man-made capital is treated differently than depreciation of natural assets. Hence, while the cost of 'using up' a machine is reflected in the net national product through depreciation allowances, the cost of 'using up' a natural asset is not. Because both a machine and a forest provide for the welfare of current and future generations, they are productive assets. Thus, according to Repetto et al (1989), these assets should be treated symmetrically in the national accounts. Such a treatment is consistent with the theoretical considerations above.

Repetto et al (1989) study Indonesia during 1971-84, a period of rapid economic growth; GDP increased 7.1% per year on average. This growth was, to a large extent, based on intensive exploitation of oil, gas, minerals, forest products and other natural resources. Repetto et al (1989) challenge the view that (given Indonesia's dependency on natural resources) GDP provides an accurate picture of the country's economic success.

As a first step, the authors' construct physical resource accounts. Specifically, they focus on three major assets: forests, oil, and soil. For each asset a physical and monetary account is constructed. A key issue is valuing the change, in monetary terms, of the asset stock. The basic approach to the economics of depreciation, outlined in 1925 by Harold Hotelling, is to analyze the present value of future services from a machine or a resource.¹⁵ Repetto et al select to use the net rent method. The depreciation allowance is equal to price minus the costs of extraction.

Forests are divided into 'primary' and 'secondary'. The stumpage value of timber in 'primary' forests is obtained by subtracting the costs of extraction and transportation from export value. The stumpage value for 'secondary' forests are calculated to be roughly half the value of primary forests.

¹⁴ There is also a "local" application of resource accounting, involving the Chesapeake Bay (USA), bordered by the states of Maryland, Pennsylvania and Virginia. See Peskin, H. (1989) "A Proposed Environmental Accounts Framework." In Ahmed, Y.J., El Serafy, S. & Lutz, E. Environmental Accounting for Sustainable Development, Washington, D.C., The World Bank.

¹⁵ Hotelling, H. (1925) "A General Mathematical Theory of Depreciation" *Journal of the American Statistical Association*, xx, 340-43.

Finally, plantation forests are provisionally assigned a value of zero, since they constitute a minor fraction of the total stock.

Hartwick (1990) has shown that the value of the change of a homogenous renewable resource should be valued at the 'marginal' stumpage value per unit (price minus marginal cost). Since the forest stock is heterogenous, i.e. price and marginal cost varies across different quality-classes, Hartwick's (1990) formula needs to be modified. If it is assumed that the stock changes symmetrically over all classes, Hultkrantz (1991) suggests using the 'average' stumpage value. Thus, for each quality-class one may use the average, rather than the marginal, costs. This idea provides some support for Repetto et al's use of average stumpage value in their calculations.

The petroleum resources are valued by subtracting the average extraction- and transportation costs from the market price of oil (f.o.b. export price). Note that one would ideally like to compute the marginal costs, but in this case using average costs appears to be an innocuous simplification.

The third and final asset considered by Repetto et al is soil. Indonesia has experienced familiar problems of a rapidly growing population. Clearing of land and clearing of hillsides has, for example, meant a erosion of 60 tonne per hectare per year, according to the authors. Their estimates of erosion are based on erosion models that relate data on topography, climate, soil characteristics and land use to erosion. The models predict, among other things, that a shift from forest to agriculture implies a soil loss of 133 tonnes per hectare. The authors also estimate that the depreciation of soil fertility is roughly the size of the annual production increase, or 4% of the value of crop production.

Repetto et al propose a measure of income, defined as 'EDP' = GDP - depreciation of natural assets. Depreciation of man-made real capital is not included in this measure. While this omission is not theoretically correct, in practice it is likely an innocuous simplification.

A summary of the findings is reported in Figure 3.

Indonesia: GDP and EDP

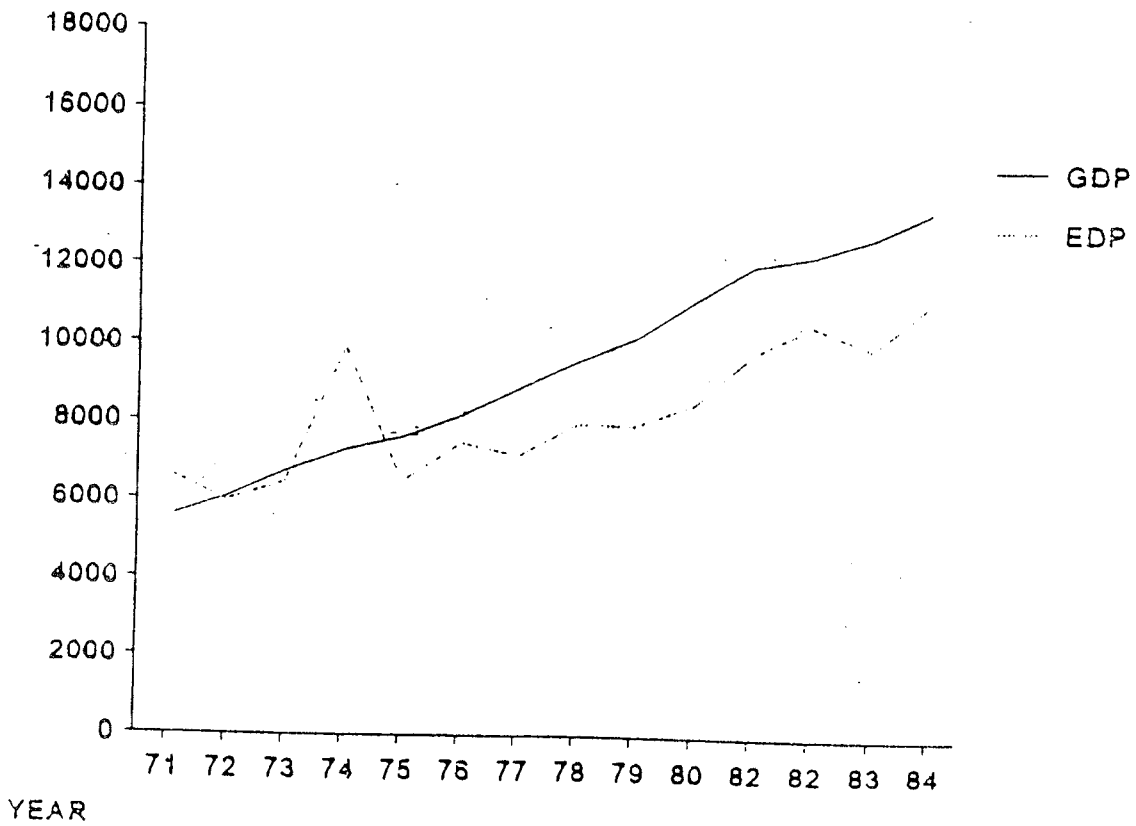


Figure 3. GDP and 'EDP' for Indonesia. Source: Repetto et al (1989).

Critiques of the study have focused on both the valuation procedures and the choice of income measure. Clarke & Dragun (1989) argue that the net rent method is not an appropriate valuation method (in the case of a renewable resource) whence decreasing the stock may be part of a program to increase future growth of the forests; compare the use of cleanings and thinnings. El Serafy also contends that the net rent method is not a correct depreciation approach. He advocates the approach which we dismissed as arbitrary.

Clarke & Dragun's point about the forest calculations can be approached from a number of standpoints. The simplest is to separate final fellings from the investment-like cleanings and thinnings in the accounting procedure. It is difficult to assess how such reclassifications affect the final results calculated in Repetto et al's study.¹⁶

If we compare Repetto et al's EDP-concept with the welfare index we proposed in section 3.5 there are a number of differences. The treatment of labor, human capital and environmental quality are main dissimilarities. It should also be pointed out that Repetto et al use gross rather than net investments in real capital.

Furthermore, one could add that Repetto and his team only concentrated on the value of timber in looking at the economics of forests. There are indications that forests play a much wider and more important role for economies. The forest is an ecological system

While Repetto et al's study has been criticized for various errors it remains the first important study to show how resource accounting can be used to shed light on particular resource allocation problems. Our review has concentrated on the 'EDP' concept presented in the report, which is only a part of the material compiled. The effort of Repetto et al to construct the Indonesian resource accounts paves the way for a wide variety of analyses pertaining to relationships between the economy and the environment. This is perhaps its most important contribution. A similar application is made for Costa Rica, see WRI (1991).

7.3 Malaysia

Vincent (1993) has examined resource use in Malaysia. Like Indonesia, Malaysia is rich in natural resources. Vincent (1993) focuses on minerals and timber, the two most important natural resources in Malaysia. A geographical breakdown of resource use shows that net investments have been positive in Peninsular Malaysia in the 1970s and 1980s, while net investments have been negative in Eastern Malaysia during the same period. While the Peninsula has depleted its natural resources, it

¹⁶ For additional critique of the Repetto et al study, see e.g. Peskin (1989).

has used the proceeds to invest in human-made capital. The total capital stock appears to be larger than in the beginning of the 1970s. The evidence on the net change of the total (measured) capital stock in the other parts of the country is somewhat mixed, although the evidence points to a future economic decline in these areas – the current level of consumption is not sustainable.

For various reasons, human capital is not included in the calculations, but substantial decreases in the illiteracy rate and significant expansions of the education system since 1970 suggests that the human capital stock has increased. This increase possibly outweighs the negative net investments in the Eastern parts.

Vincent's (1993) analysis can be seen as an attempt to check whether different parts of Malaysia satisfies Hartwick's rule. This rule says that if production possibilities in a country with only non-renewable resources are such that it is feasible to sustain positive consumption, then the economy can enjoy the maximum constant consumption, if the resource rents are invested in reproducible capital. Given such an objective, much of Vincent's analysis is consistent with our discussions on how to value resource stocks. There is one difference, however. According to Vincent (1993, p.8), discoveries should not be included measures of net depletion of a nonrenewable resource. As I have already said we should include the net change of the stock, if it can be predicted with some certainty that explorations lead to new discoveries. I will discuss this issue in more detail tomorrow.

7.4 Swedish forests

Hultkrantz (1991) made an attempt to adjust the sectoral forest accounts by including several non-priced services provided by forests. The following table illustrates the components included in his analysis:

Table 5. Components Included in Modified Forest Accounts

Yield	Maintenance	Stock
Timber	Maintenance	Forest Inventory
Harvest of Berries		Berry-yielding Herbs
Mushroom		Mycclium
Meat (bag)	Game Protection	Game Population
Recreation	Various Activities	Various
Biodiversity-	Fauna/Flora Protection	Survival Conditions
Effects on Hydrological flows	Measures that affect runoff	Forest Inventory, bare lands, ditches, etc.
Fixing of Carbon	Silviculture and Boarding (non-harvesting)	Carbon Pools
Buffering of Acid Rain, Tree Nutrition	Liming, Fertilization	Content of exchangeable base cations in soil and vegetation
Nitrogen Leaching	Construction of nitrogen sinks	Nitrogen-fixing capacity
Reindeer Forage		Lichen Stocks

Source: Hultkrantz (1991).

To the extent possible, Hultkrantz (1991) utilizes market prices to evaluate each component. Such data is available on timber, berries and mushrooms. The value of meat from hunting and recreational values, are obtained from a contingent valuation study. Biodiversity is valued by considering the area of protected land that must be set aside to protect biological diversity, and then computing the opportunity costs. The hydrological effects, e.g. forest absorption of water that could have been used for power generation, are not valued explicitly. Carbon fixing is valued by using the effluent fee of carbon dioxide (c.f. our theoretical discussion above). Note that Hultkrantz (1991) counts the increase of growing forest stock twice. First, the timber value and then the value of carbon fixing. The annual depletion of exchangeable cations in forest soils can be compensated by liming, and this cost is used as a proxy. For lack of data, nitrogen leaking is not considered explicitly. Forests (in the North of Sweden) also provide reindeer forage. Because changes in lichen stocks are not included in

the current accounts, so Hultkrantz (1991) utilizes studies on opportunity costs to obtain a value of the change in stocks. His final results are reported in the following table.

Table 6. Modified NNP accounts for income from Swedish forests, 1987

Market value of Timber	18.63
Inputs from other sectors	-3.14
Stock growth	3.8
Silviculture	-1.55
<i>Subtotal 1</i>	<i>17.75</i>
Berries	0.5
Mushrooms	0.55
Meat from game	0.47
<i>Subtotal 2</i>	<i>1.52</i>
Biodiversity	0.6
Carbon Pools	3.8
Exchangable cations in soil	-0.6
Lichen Stocks	-0.02
<i>Subtotal 3</i>	<i>2.58</i>
TOTAL NET INCOME	21.85

Source: Adapted from Hultkrantz (1991, table IV, p. 390). The figures are in billion SEK.

7.5 Regional Colombean accounts.

Common for all the studies I have review is that they have focussed on very tangible outputs from forests - timber, berries, etc. Repetto et al in their studies of Indonesia and Costa Rica extended however, the role of forests to the control of the soil layer. That this is important has been shown by Molinas who in an unpublished study - it is now being translated into English - showed that this function of the forest may be extremely important. Using ecological information he calculated the erosion of soils at the rather steep sides of hills in a specific region in Colombia that would follow clear cutting the slopes. The effects on the rivers running in the valleys were then calculated. The increased turbidity of the waters made them unfit for human consumption which increased the cost of water supply to the villages in the area. In fact, the value of the forest in controlling erosion and water quality was higher than the value of the potential timber output. This shows the necessity of including a rather wide set of functions and services of ecosystems in order to make realistic and comprehensive estimates of the systems contributions to the net national product

7.6 The SEEA

We end this section by commenting on the System of Integrated Environmental & Economic Accounting, which has been developed by the UNSTAT, the Statistical Division of the United Nations. This system complements the current SNA in two important respects; (i) Depletion of natural resources in both production and final demand and (ii) changes in environmental quality. The SEEA also includes a broader concept of capital, this includes not only man-made capital but also natural capital.

The SEEA contains both physical and monetary accounts. The physical accounts have a structure which is similar to the Norwegian accounts we presented in section 5.2.¹⁷ The asset-boundary is very general and includes, in principle, all assets (United Nations (1993, p.8), referred to as "the Handbook" in the sequel). It is acknowledged that an application of the SEEA probably needs to

¹⁷ The differences between material/energy balances and the French and Norwegian systems are, according to the Handbook (1993 (p.75)), e.g. less detailed spatial description of transformation processes (c.f. the French system) and a more comprehensive description of economic activities and their use and production of residuals.

restrict the number of assets included. In any case, the asset boundary is much wider compared to the ordinary SNA.

In transforming the physical data to monetary units, the Handbook discusses three different approaches: (i) Market valuation, (ii) Direct Methods (e.g. Contingent Valuation) and (iii) Indirect Methods (e.g. "environmental protection costs").¹⁸ The most important of these in the SEEA are the indirect methods, in particular the "maintenance cost concept". While the exact definition of this concept is unclear, it is stated that "The (hypothetical) maintenance costs are -- mainly prevention costs that would have been necessary to prevent negative impacts of economic activities on the environment and/or to meet given sustainability standards --" (Handbook (p.19)).

As illustrated in the studies of Mexico and Papua New Guinea above, the SEEA also suggests an Environmentally adjusted Domestic Product (EDP). It is defined (Bartelmus (1993, p.67)) as:

$$\text{EDP} = \text{Final Consumption} + \text{Net Capital Formation} + \\ \text{Net Exports of goods and services} + \text{Net Exports of residuals}^{19}$$

The SEEA integrates use/value added tables, balance sheets for environmental and economic assets, and tables for intermediate, final consumption and capital accumulation. The structure is as follows:

1. Opening Stocks (produced and non-produced)
2. Use/Value added tables (GDP, NDP, EDP)
3. Supply-tables (Goods and Services, Imports of residuals)
4. Revaluation and other volume changes
5. Closing stocks

Defensive expenditures are identified and classified in a number of ways. The argument for not deducting them from EDP is, according to Bartelmus (1993, p. 59), based on *reductio ad absurdum* - food could, for example, be considered a defensive expenditure against starvation and "in the limit" the adjusted national product is zero.

¹⁸ The terminology used in the Handbook for different valuation methods is somewhat unusual, in that Hedonic pricing and travel cost methods are called "Direct Methods" (Handbook (1993, p. 17)). In the literature, these are typically called "indirect", because the value of the environmental resource is revealed indirectly from associated market goods.

¹⁹ In the Handbook of SEEA, considerable doubt is expressed regarding the possibilities of calculating net exports of residuals. See sections, 78, 110, 192, 216, 243 and 292 in the Handbook for further discussions.

Regarding valuation of non-financial assets, the SEEA discusses three main approaches; (i) actual prices of natural assets; (ii) present value of expected net proceeds and (iii) the net-price method (used by Repetto et al (1989)). El Serafy's approach is considered for depletion of (exhaustible) mineral resources. The Handbook suggests using different approaches for different assets. For changes in land quality, market prices (to the extent it is possible) should be used. For depletion of natural assets such as wild biota, subsoil assets or water, the net price method "could be used" (p. 61). For forests, stumpage values are considered appropriate.

The Handbook is a work-in-progress report. Several issues remain to be clarified and discussed before the system matures in to a powerful vehicle in exploring and understanding the linkages between the economy and the environment. Nevertheless, its appeal to economists is limited by the fact that the welfare economics foundations are weak. The presented EDP-concepts have not been shown to correspond to any sign-preserving measure of welfare change. This severely limits the interpretation of the adjusted national products in the SEEA and therefore the value of the system itself.

7.6.1 Mexico

Van Tongeren et al (1991) present an integrated environmental and economic accounting system of Mexico.²⁰ The study followed the guidelines set forth in UNSO's draft handbook on environmental accounting. Oil depletion, deforestation, land use and environmental asset depletion (air & water pollution, soil erosion, ground water and solid waste) were focused upon. In the sense that physical accounts were established first and then later transformed into monetary accounts the general strategy followed closely that of the Indonesian study. Two environmentally adjusted domestic products (EDP) are calculated. The reason for presenting two types of EDPs is that EDP1 is based on market transactions, while EDP2 includes calculations involving less generally agreed upon principles (such as the avoidance cost method).

Valuation of changes in oil and timber stocks was carried out by using both the net rent method and El Serafy's approach. In the second case, one needs to calculate the discounted sum of depletion allowances necessary in keeping income constant. The study year (1985) gives different results for the two approaches; net rent is 1162 pesos/barrel, the depletion allowance is 160 pesos/barrel.

Average stumpage values for forests were computed to be 21.5 and 1.6 pesos/m³ respectively.

The Van Tongeren et al study also includes environmental quality changes. Besides valuing soil

²⁰ The SEEA-system has been tested on New Papua Guinea (see below) and Thailand.

erosion and solid waste generation (by households), the authors also include sulfur dioxide, Nitrogen Oxide, Carbon Monoxide and emissions of suspended particulates. Land erosion was valued at the cost of fertilizer to maintain the productivity of the land. Ground water loss was valued at the cost of re-injecting water back into underground water reservoirs. Finally, water and air pollution were valued at the cost of reducing such pollution "to acceptable levels" (p. 7).

The main findings of the monetary valuations are summarized in the following table:

Table 3. Conventional and Environmental Accounts, Mexico 1985

	Conventional Accounts	EDP1	EDP2
NDP	42.1	39.7	36.4
EDP/NDP	*	0.94	0.87
C/NDP	0.83	0.88	0.96
CAP	4.7	2.3	-0.85

Source: Van Tongeren et al (1991), p. 24.

Figures are in Billion pesos.

C = Consumption

CAP = Net Capital Formation

EDP1(2) = Environmentally Adjusted Net Domestic Product (see text for details)

NDP = Net Domestic Product

EDP1 includes degradation of natural capital. By subtracting these costs from NDP, one finds that the value of this degradation is about 6% of NDP. If additional environmental damages are taken into account, the adjusted Mexican income is about 13% less than the conventional NDP. It can also be seen that consumption is the major component in the studied income-measures. Computation of changes in the capital stock (net) gives different results, depending upon which measure is selected. The most comprehensive measure, EDP2, suggests a negative build-up of real capital in Mexico. Both EDP1 and EDP2 differ substantially from our suggestion of how to adjust the national product. First, the wage-bill and the human capital stock is not given a correct treatment in this study. It is difficult to say, based on the data in the report, how a correct treatment would have changed the conclusions. Second, new finds of oil are not included in the net change of the oil stock. As in the Vincent (1993) study, this is not a correct treatment. Third, changes of the stock of forests are only accounted for if the harvests are larger than the maximum sustainable yield. No compelling

arguments are presented to support that treatment. Several similar points can be made, but they all point in one direction, namely that the system is ad-hoc. The proposed concepts of adjusted national products may have some connections to a welfare index, but this is very difficult to know. One example of the generic problem in this study is the following quote (p.22): "It should furthermore be noted that in the derivation of Y_{n2} [EDP2], an additional deduction has been made for environmental services produced by the government in the form of sanitation services. They are treated as intermediate consumption of (domestic) household protection activities." Again, no compelling reasons are presented to support this argument.

7.6.2 Papua New Guinea

Bartelmus et al (1992) provide an analysis of an integrated economic and environmental accounting system for Papua New Guinea, using the SEEA as the main tool. The country under study is rich in natural resources, but has only a small industrial base. A small number of mines contribute to 60 % of the export earnings from copper, gold and silver. Following closely the case-study of Mexico, Bartelmus et al (1992) use both the net rent method and El Serafy's method in calculating the value of resource-depletion due to mining. While forests cover about 75 % of the total area of Papua New Guinea, the forest industry is relatively small, providing about 4 % of GDP and roughly 8-% of total export value (Bartelmus et al, p.20). Following the Mexican study, a depletion allowance is not calculated, as the rate of forest cutting is judged to be below the sustainable rate.

The institutional structure of ownership in NPG allows an unusual approach to valuing certain environmental damages in monetary terms. Land, water, and related natural resources are owned by tribal groups and clans. According to Bartelmus et al these groups, or rather their communities, bargain for compensation for resource exploitation following long-time tradition in the country. Such information has been used to value the impact of the construction of hydroelectric power plants.

The main findings are summarized in Table 4.

Table 4. Adjusted National product for Papua New Guinea, 1986-1990

	1986	1987	1988	1989	1990
NDP	2313	2569	2862	2698	2760
EDP1	2187	2359	2755	2673	2579
EDP2	2133	2351	2697	2614	2521

Source: Bartelmus et al (1992), p. 35. Figures are in million Kina.

As can be seen from the table, the differences between the various income measures are very small. This is presumably due to the fact that the country is not, to any significant extent, industrialized. About 80% of the population lives in remote villages and does not take part in ordinary market transactions. In a sense, therefore, the presented NDP, EDP1 and EDP2 measures cover only 20% of the population.

This study has the same generic weakness as the Mexico study. The conceptual foundations, from a welfare-theoretic point of view, for the suggested EDP-measures are weak (or even non-existent). It is difficult to tell exactly what question(s) the EDP-measures are supposed to answer.

8. Concluding remarks

I have in this paper tried to explore the consequences of basing resource accounting on firm theoretical grounds. I hope to the arguments have been convincing that if certain technical restrictions are met, for any conception of social well-being, and for any set of technological, transaction, information, and ecological constraints, there exists a set of shadow (or accounting) prices of goods and services that can be used in the estimation of real net national product (NNP). This holds no matter what is the basis upon which social well-being is founded. On the basis of this I hope I have shown how an accounting system can be constructed using conventional tools of welfare economics.

The scrutiny of existing applications showed that the approach I have tried to outline is different from the ones currently used. This should not be surprising, given the fact that resource accounting is still in its formative stage. Nevertheless, it is important to begin with the fundamental question: what is it that we want to measure? If we want to measure well-being, then our suggestions follows naturally from received welfare economics. My fundamental point is that measurement without theory is as dangerous in resource accounting as elsewhere. Therefore I agree whole-heartedly with Erik Lindahl, who made exactly the same point, when he developed his accounting system in the 1930s.²¹ Without supporting theory we run the risk of developing accounting systems that are inherently useless when it comes to increasing our understanding of the proper husbandry of our environment and natural resources.

²¹ Lindahl's contributions to national accounting are described in Kriström (1994).

Appendix

1. Optimal paths

Received theory on national income accounting and natural resources is based on the optimal growth model. Along an optimal development path, there will be a price system and this system of imputed prices will define the proper net national product. This idea was first proposed by Weitzman (1976) and later applied to the problem of the inclusion of environmental resources in national accounts by Hartwick (1990), Mäler (1991), Dasgupta and Mäler (1992) and many others. In the form it will be presented here, it was first outlined in Mäler (1974) and in Dasgupta & Heal (1979). I will explore that approach in a series of simplified models.

1.1. Flow of services

I will start by assets and instead focus on the flow of services from consumer goods, the environment, and leisure. Let L be the total amount time available per period. It can be used for labour L_1 and leisure L_2 . Thus,

$$L_1 + L_2 = L.$$

The following analysis can be done by letting C be a vector of consumption goods and services and let Q be the vector of flow of environmental services, but no essential insights are lost if we consider composite goods C and Q . Let p be the price of C and denote the wage rate w . Finally, let other incomes be I . The budget equation is

$$pC = wL_1 + I.$$

I will consistently neglect income distribution, not because it is unimportant but because I do not believe that national accounting systems are well adapted to include such considerations. Because of this I will assume that there is only one individual in the economy. Let

$$U(C, Q, L_2)$$

be the utility function of that individual.

A change from (C^0, Q^0, L_2^0) to (C^1, Q^1, L_2^1) corresponds to a change in utility:

$$\Delta U = U(C^1, Q^1, L_2^1) - U(C^0, Q^0, L_2^0)$$

ΔU is the correct non-linear measure of the change in welfare. However, we want a linear measure and we therefore linearize (using subscripts to denote partial derivatives):

$$\Delta U \approx U_C(C^1 - C^0) + U_Q(Q^1 - Q^0) + U_L(L_2^1 - L_2^0).$$

We evaluate the utility function either at the optimum or at some other point, the importance being which prices we use. As explained yesterday we can use either the prices corresponding to a global optimum or the local prices. I will come back to this in the end of the lecture. Let the consumption good be the numeraire (so that $p=1$). Then dividing the above expression by the marginal utility of consumption and using the first-order conditions for an interior optimum for the consumer we have;

$$\Delta NNP = (C^1 - C^0) - w(L_2^1 - L_2^0) + q(Q^1 - Q^0),$$

where NNP is the Net National Product and $q (=U_Q/U_C)$ is the marginal willingness to pay for environmental services. Using the budget equation we find that

$$\Delta NNP = I^1 - I^0 + q(Q^1 - Q^0).$$

Thus, (the change in) NNP case corresponds to the change in "other" incomes and the value of the change of the flow of environmental services. This proves the proposition I made yesterday that the return on raw labour should not be included in NNP. I will return to this issue when I discuss a different approach to the construction of linear index.

Let me now assume that Q corresponds to the environment, but that the individual can improve that environment by allocating resources to "defensive" measures - increased insulation against noise pollution, cleaning up beaches, etc. By using the vector Y of marketed goods and services, the vector Q can be transformed into the vector Z according to the production function

$$Z = g(Y, Q).$$

The utility function is (we now neglect labour income)

$$U = U(C, g(Y, Q))$$

To simplify exposition, we can without loss of generality let Y and Z be scalars. The budget constraint is given by

$$p_C C + p_Y Y = R.$$

Using a linear approximation and converting to money units as above, we find that

$$\Delta NNP = (C^1 - C^0) + p_Y(Y^1 - Y^0) + q(Q^1 - Q^0)$$

This shows that the defensive expenditures should not be subtracted from the NNP measure. The confusion that can be found in the literature stems from the fact that we can also write ΔNNP as

$$\Delta NNP = (C^1 - C^0) + p_Z(Z^1 - Z^0),$$

where p_Z is marginal willingness to pay for the "transformed" environment Z . Thus, one has to be careful about how one defines the flow of environmental services. In most cases, it seems most appropriate to use the "external" environment, e.g. the noise level outside a building, the pollution before a cleanup etc. This would correspond to the use of the Q -variable. In some cases, it is possible to estimate q from estimates of the defensive expenditures, $p_Y(Y^1 - Y^0)$. However, that is not always the case.²²

Let us now consider an open economy which exports pollution (but so far no goods and services) and which also imports pollution. Let there be two countries S (Sweden) and F (Finland). Let the utility functions in the two countries be $U^S(C^S, Q^S)$ and $U^F(C^F, Q^F)$, respectively. Assume that emissions (M) are generated in the two countries by producing the consumption goods:

$$C^i = \phi^i(M^i), \quad i = S, F.$$

Assume further that the transport of the pollutants across borders can be described by a linear matrix:

$$Q^i = \alpha_{iS} M^S + \alpha_{iF} M^F, \quad i = S, F.$$

We can now define a number of different net national product measures. Proceeding as above, invoking a first-ordering approximation and converting into money units, the change in welfare in S from all changes during a period is,

²² See Maler et al (1994).

$$\Delta NNP^S = (C^{S1} - C^{S0}) + q^S(Q^1 - Q^0) = (C^{S1} - C^{S0}) + q^S(\alpha_{SS}(M^{S1} - M^{S0}) + \alpha_{SF}(M^{F1} - M^{F0}))$$

and correspondingly for the other country. With this measure, it is easily seen that if we add the measures for the two countries, then we will end up with a measure of the welfare change for the two countries together. This definition of NNP is therefore internationally consistent.

A different definition would be to define NNP in terms of the change in welfare from activities in one country, irrespective of where the welfare is changing:

$$\Delta NNP^{SF} = (C^{S1} - C^{S0}) + q^S \alpha_{SS}(M^{S1} - M^{S0}) + q^F \alpha_{FS}(M^{S1} - M^{S0}).$$

and correspondingly for the other country. Once again, the definition is internationally consistent and if we add the NNP for the two countries, we will again end up with the welfare change for the two countries together. The difference between the two definitions is similar to the usual distinction between national product and domestic product.

1. 2. Human capital -

Let me now introduce one stock - human capital. Total production is given by the production function

$$Y = F(TL),$$

where T is the stock of human capital and L is the number of hours worked. Total production is allocated to investment E in human capital and to consumption C.²³ Let us assume that the dynamics of the stock can be written

$$dT/dt = \mu ET$$

where μ is a constant. The individual maximizes the present value of his future utilities, i.e.

$$\text{Max} \int_0^{\infty} U(C, L) e^{-rt} dt$$

subject to

²³ The analysis is easily extended to cover other types of human capital models. We focus on the simplest one here.

$$C = F(TL) - E$$

$$dT/dt = \mu ET.$$

It is important to note that r is a utility discount factor, which need not be equal to a market discount rate.²⁴

The current value Hamiltonian for this optimal control problem is

$$H = U(F(TL) - E, L) + p_T \mu ET$$

with p_T denoting a multiplier. The optimality conditions are

$$U_C TF'(TL) = -U_L$$

$$U_C = \mu p_T T$$

The accounting price on T is determined by

$$dp/dt = rp_T - LF_T(TL) - \mu p_T E.$$

The Hamiltonian now plays the same role as the utility function played in the previous section. It incorporates both the flow of current services and the value in the future from the current addition to the stock by investments. Thus, the Hamiltonian is the correct non-linear welfare measure. In order to get a linear measure, we linearize it. Using consumption as the numeraire and dividing by the marginal utility of consumption we have,

$$NNP = C - wL + (p_T/U_C)dT/dt$$

Once again, we see that the wage bill should be deducted and the difference between C and wL reflects the return on human capital.

1. 3. Stocks of environmental resources

Let S be a vector of stocks of resources. These resources are harvested at the rate X . Let the dynamics

²⁴ See Dasgupta & Mäler (1991) for a detailed discussion of the implications of this fact.

of the resources be represented by the growth functions $g(S)$. Thus

$$dS/dt = g(S) - X$$

For exhaustible resources, the corresponding growth is of course zero and let us begin by exploring the implication of this for NNP in an extremely simple case. Suppose a country exports its non-renewable resource in return for a consumption good. We assume that it faces the following maximization problem;

$$\text{Max} \int_0^{\infty} u(C_m) \exp(-rt) dt$$

$$dS/dt = -X$$

$$p_x X - q_m C_m \geq 0$$

$$S(0) = S_0 > 0$$

$$\lim_{C_m \rightarrow 0} \partial U(C_m) / \partial C_m = \infty$$

C_m is the consumption of the imported good, r is world-market interest rate, p_x is the export-price of X in foreign currency and q_m is the price of the imported good (in foreign currency). The last constraint is the

budget-constraint for the country; it is the balance-of-payment in foreign currency when we assume that no capital markets exists. In this simple model, the country cannot save by selling the resource on the world-market by investing the proceeds from the exhaustible resource. It will be assumed that the market for the exhaustible resource is in equilibrium for all t . To solve the maximization problem, construct the following Lagrangian;

$$L = U(C_m) - \gamma X + \zeta (p_x X - q_m C_m) = H + b(p_x X - q_m C_m)$$

where γ and ζ are multipliers. The first-order conditions are;

$$\partial U / \partial C_m = \zeta q_m$$

$$\gamma = \zeta p_x$$

$$\zeta > 0 \quad (= 0 \text{ if } p_x X - q_m C_m > 0)$$

$$(d\gamma/dt)/\gamma a = r$$

It is seen that the marginal utility of consuming the imported good is equal to aq/p ; the benefits of consuming the imported good today balances on the margin with the benefits forgone 'tomorrow' of keeping the unit in the ground. Proceeding as above we find that;

$$H/(\partial U/\partial C_m) = C_m - (p_x/q_m) * X = 0$$

In other words, NNP is equal to zero; a common result in 'cake-eating' models. In fact, this equation simply states that the country must obey its budget-constraint in every period. Sooner or later, exports must go to zero and it is impossible to find a sustainable consumption path (at given prices). Dasgupta & Mäler (1991, p. 109) gives a verbal description of the above model in the "cake-eating" tradition, concluding "Such an economy cannot manage a positive, sustainable consumption path. It is this fact which is reflected in NNP, when correctly measured." The key insight is that NNP includes information not only about the welfare of the present but also of the future; this information is merged into the market-prices.

Sometimes it is possible to discover more of a resource. Assume that this process is deterministic, i.e. that one knows with certainty that following a certain amount of investments in exploration, the stocks will increase in a deterministic fashion.²⁵ This idea can be incorporated by including Y used in exploration activities in the growth function. For some resources, Y can also be interpreted as expenditures on maintenance, fertilizers etc. Thus let us write

$$dS/dt = \theta(S, Y) - X$$

The production in society is described by the production function

$$W = F(K, S, X),$$

where K is the stock of real capital. We thus exclude labour in this particular study as it would not give any further insights.

²⁵ When discoveries are stochastic the analysis needs to be modified as shown in Dasgupta & Mäler (1991). See also the main text for a verbal description of this case.

Total output can be used for consumption C , investment in real capital I and in investments in environmental resources X .

$$W = C + I + Y.$$

The utility of the representative individual is $U(C, S)$. We thus neglect the flow of environmental services since that flow has been discussed in a previous section. As before, we assume that the individual is maximizing the present value of future utilities

$$\text{Max } \int_0^{\infty} U(C, S)e^{-\delta t} dt.$$

subject to the conditions above. The current value Hamiltonian is

$$H = U(C, S) + p_K dK/dt + p_S dS/dt.$$

The accounting prices follow the differential equations:

$$dK/dt = \delta K - \partial H / \partial p_K$$

$$dS_i/dt = \delta S_i - \partial H / \partial p_{S_i}$$

The NNP can now be written, again using consumption as a numeraire,

$$\text{NNP} = C + (U_S/U_C)S + (p_K/U_C) dK/dt + (p_S/U_C)dS/dt.$$

The net national product is again equal to the value of the consumption plus the value of the net change in the stocks of all resources and the "flow" value of the stocks S . This last value occurs because we have assumed that the individual has preference for the stock of some resources, such as biodiversity, such as the population of blue whales etc.

Note that the NNP equals the current utility value plus *the value of the change in the resource stock* and not the change of the value of the stock. Thus capital gains should not be included. However, this result depends critically on the assumption that the Hamiltonian is stationary. If there are exogenous changes in say international prices, then of course some countries may gain and other will lose. In this case capital gains should be included, as has been shown by Sefton and Weale.

The above analysis can now easily be adapted to study the case where a country can trade a non-renewable resource in return for a renewable one. Specifically, assume that a country can export its non-

renewable resource and use an international capital market to invest the proceeds. To analyze this case, the current account surplus will be defined as follows;

$$dB/dt = rB + p_x X - q_m C_m$$

where B denotes the country's foreign assets. The country is assumed to obey its intertemporal budget-constraint in the sense that;

$$\lim_{T \rightarrow \infty} B_T \exp(-rt) = \lim_{T \rightarrow \infty} \int_0^T (p_x R - q_m C_m) \exp(-rt) dt = 0$$

Thus, in the long run the present value of the net trade-surplus must go to zero. Proceeding as above it is easy to see that we should deduct that value of the decrease in the resource stock and add the value of the change of the stock B when constructing the welfare measure. For additional details, see Kriström (1993)

1. 4. NNP and sustainable development

I will end this survey of existing approaches by commenting on the relation between an adjusted national product measure and its possible links to a notion of sustainable development. We begin this analysis by using properties of time-independent Hamiltonians. Consider

$$H = U(C, S) + p_K dK/dt + p_S dS/dt$$

I will now prove that this Hamiltonian is time-independent and then use this result to derive a notion of sustainable development. Thus, totally differentiate H with respect to time to obtain,

$$\frac{dH}{dt} = \frac{\partial H}{\partial K} \frac{dK}{dt} + \frac{\partial H}{\partial p_K} \frac{dp_K}{dt} + \frac{\partial H}{\partial S} \frac{dS}{dt} + \frac{\partial H}{\partial p_S} \frac{dp_S}{dt} + \frac{\partial H}{\partial u} \frac{du}{dt}$$

where u is the vector of controls, I, Y and C. Using the optimality conditions, one finds that;

$$\begin{aligned} \frac{dH}{dt} &= \left(-\frac{dp_k}{dt} + rp_k\right) \frac{dK}{dt} + \frac{dK}{dt} \frac{dp_k}{dt} + \left(rp_s - \frac{dp_s}{dt}\right) \frac{dS}{dt} + \frac{dS}{dt} \frac{dp_s}{dt} = \\ &= r\left(p_k \frac{dK}{dt} + p_s \frac{dS}{dt}\right) = r(H^* - U) \end{aligned}$$

which shows that the Hamiltonian is time-independent, or that the total time-derivative of H is equal to the partial time-derivative. Using this result one could argue (see Solow (1986)) that if prices are constant during the period (i.e. we consider only marginal changes), then we could for that period define an aggregate capital stock;

$$K^* = p_k K + p_s S.$$

If that stock is non-decreasing, then the Hamiltonian will also be non-decreasing. This reflects what has been called sustainable development. Furthermore, it follows from the discussion above that (with constant prices)

$$\dot{H}^* = rK^*$$

where H^* is the maximum value of the Hamiltonian. Thus, if we are at an optimal trajectory (and if the time-span is short enough (constant prices)), then the value of the Hamiltonian can be interpreted as the return on the aggregate capital stock.²⁶ This interpretation is not possible if the economy is far from the optimal trajectory. If the economy is at an optimal trajectory then it follows from the above that

$$\int_t^{\infty} H_t^* e^{-r\tau} d\tau = \max \int_t^{\infty} e^{-r\tau} U d\tau$$

so that H^* is the maximum constant stream of utility the economy can have. This was first derived by Weitzman for an economy with only a consumption good and a capital good and when the utility was linear in consumption. Furthermore, Weitzman did not use an optimal trajectory but looked at a competitive economy. I applied the optimal control approach to the same problem I just now have

²⁶ See Aasheim (1993) for detailed investigations of this interpretation.

discussed in this paper a couple of years ago (Måler 1991), and since then there has been a huge production of papers on this topic. In one strand of papers, the Weitzman result has been extended to situations when the pure rate of time preference is variable. This has in particular been pursued by Geir Asheim, Oslo. In another strand of papers, technical change and endogenous growth have been included. This has been pursued by Thomas Aronson and Karl-Gustaf Löfgren in Umeå. There is, however, one substantial difference between these extensions and the analysis I have presented to you. I have been interested in finding a linear social cost-benefit rule and in the search for such a rule, Weitzman types of results were obtained as interesting sideproducts. These sideproducts were not, however, the main products of the kind of research that professor Dasgupta and I initiated a couple of years ago. The more recent studies have not been interested in the questions we were interested in, but only in obtaining extensions of Weitzman's result. Although very interesting, I don't believe they have made contributions to the design of accounting systems, but only to the interpretation of some measures that never will be included in an accounting system.

2. Basic framework with local prices

The framework I have discussed above can be criticized for relying on an optimal growth path as a vehicle to establish both an accounting system and the imputed prices to be used in finding the appropriate values of flows and stocks to be included in the system. Therefore, I would like to present a different approach, which never the less gives approximately the same results as those presented earlier. This new approach is based on the use of local prices, i.e. prices that reflect the marginal valuations of the individual along the real path and not along a hypothetical growth path. The basic idea is approximate linearly the social welfare function directly, before any attempt to optimize is made. I used this approach already in 1974 for establishing a very simple relation between flows of environmental amenities and net national product. However, as far as I know, no one has developed the theory further. I want present to you an outline of such an approach. Unfortunately, my analysis is not complete and there are some results that at this moment are only conjectures and not proven theorems. For convenience, I will change to discrete time.

2. 1. A consumption-capital model

Let $U(C_t)$ be the instantaneous utility function where C_t is the consumption in period t .

Let $f(K_t, L_t)$ be the production function, where K_t is the capital stock and L_t is the input of labour. The output can be used for consumption and investment in capital, i.e.

$$C_t + K_{t+1} = K_t + f(K_t, L_t).$$

Here we have not accounted explicitly for depreciation of capital, but the production function f may be interpreted as the net output production function.

Let the social welfare V be defined as the discounted present value of future utilities, that is social welfare is defined as

$$V = \sum_0^{\infty} U(C_t, L_t)/(1+r)^t.$$

This means that I do not consider distributional issues,

Note, that I do not assume that V is maximized. On the contrary, the basic idea behind the following presentation is that the net national product should be defined as a linear approximation to the social welfare function irrespective whether we are on an optimal trajectory or not. This will become clear in a short while.

Assume that we are given a time path of consumption and labour supply $\{C_t, L_t\}$. Associated with this consumption path is a corresponding path of capital stocks $\{K_t\}$. A project is a perturbation of these paths. Let us look at the particular perturbation $\{dC_t, dL_t\}$ and let us find out the effect of this perturbation on social welfare V .

$$dV = \sum_0^{\infty} [U'_c(C_t, L_t)dC_t + U'_L(C_t, L_t)dL_t]/(1+r)^t.$$

Let the present value of the marginal utility of consumption in period t , with consumption in period 0 as the numeraire be

$$p_t = [U'_c(C_t, L_t)/U'_c(C_0, L_0)] * 1/(1+r)^t.$$

and let the present value of the marginal (dis)utility of labour in period t be w_t . Then

$$w_t = - U'_L(C_t, L_t)/U'_c(C_t, L_t) * 1/(1+r)^t.$$

It follows that $p_0 = 1$. It is obvious that p_t can be interpreted as the imputed price on consumption in

period t with consumption in period 0 as the numeraire and that w_t can be interpreted as the imputed price on labour.

The index we are going to define is simply $dV/U'(C_0)$, i. e., the change in welfare expressed in the numeraire, that is consumption in period 0. We will denote this index by $dNNP$, i. e. the perturbation in net national product.

It now follows that

$$dNNP = dC_0 - w_0 dL_0 + dI_0 + \sum_t (p_t f'(K_t) + p_{t+1} - p_t) dK_t + \sum_t (p_t f_L - w_t) dL_t.$$

Here I_0 is the increase in the capital stock in the first period, i. e. the net investment in that period and dI_t is the perturbation in net investment in the future, i. e.

$$dI_t = dK_{t+1} - dK_t.$$

The last sum represents a measure of the extent labour is not used efficiently. Irrespective of whether the imputed value of the marginal product equals the imputed wage or not, we could make the argument that our index should only incorporate current projects and not projects in the future (that is projects or perturbations that are not due to decisions made today). This means that future perturbations in the employment of labour should be set equal to zero. Note that we cannot use this argument for capital as the future capital stock will depend on current investment decisions. Thus there will be future perturbations in the capital stocks due to decisions made today.

The second last sum represents the deviations from an efficient intertemporal allocation. Each term in that series is

$$p_{t+1} - p_t + p_t f'(K_t).$$

Assume that we buy one unit of the capital good in the beginning of period t . This will cost us p_t . During period t , the return on this unit will be $p_t f'(K_t)$ and in the end of the period t we will have a unit of capital worth p_{t+1} . Along an efficient investment path, it is clear that it should not be possible to make any further gains by buying more capital and p_t must therefore be equal to $p_{t+1} + p_t f'(K_t)$. If we are following an efficient investment path (which does not necessarily mean that we are on an optimal path, as C_0, L_0 need not to be chosen optimally) the two sums in the expression for $dNNP$ will be zero and

$$dNNP = dC_0 - w_0 dL_0 + dI_0.$$

This expression is rather interesting. It shows that along an efficient path, the wage bill should not be included in the NNP index (or rather the cost of labour valued at the shadow wage rate). The intuition should be clear. We are looking at marginal changes and at the margin, leisure is valued the same as consumption. Thus an increase in labourtime that increases consumption will be completely offset by the reduction in leisure. Obviously, this needs to be modified if the economy is not moving along an efficient trajectory. We will return to this later.

Let us, however, not make the assumption of efficiency. In order to find out the actual effect on welfare, one has to know something about the future path of capital accumulation, and in particular the impact on future net investments from the change today. This is important. We are looking at an index that tells us the change in welfare from actions in the current period and not from actions in future periods. Therefore, what are the actions in the current period? They are dC_0 and dI_0 . If these changes are small, it seems reasonable to assume that $dK_t = dI_0$ for t greater than zero, i is constant over time. It is easy to see that in this case we have

$$dNNP \approx dC_0 + \left\{ \sum_{t=1}^{\infty} p_t f_k \right\} dI_0$$

Thus the change in NNP due to the perturbation in investment in period 0 is equal to the change in current consumption plus the change in netinvestment multiplied with a shadow price that reflects the present value of future returns on the change in the net-investment.

Why should not the future investment path be efficient? There are obviously many reasons for that - imperfect or missing capital markets, missing risk markets, government policies. Let us study one government policy in some detail, namely taxes on capital income.

Assume that the government has imposed tax on return on capital with the rate s_c . The total marginal return on investments in period t is $p_t f_k(K_t)$. The private return is only $(1-s_c)p_t f_k(K_t)$ and the revenues for the government is $s_c p_t f_k(K_t)$. The government uses these revenues to buy the aggregate good and provides this as a public good, G_t , to the citizens. The utility function is

$$U(C_t, G_t).$$

It is now possible to show that if this tax is the only imperfection in the capital markets, then we would once again get the result that

$$dNNP = dC_0 + dI_0 + \mu_0 dG_0$$

where μ_0 is the shadow prices on public expenditures. If our governments are wise, they will obviously increase these expenditures until this shadow price equals the cost of the expenditures, i.e. until the shadow price equals 1. If that is the case, we have

$$dNNP = dC_0 + dI_0 + dG_0.$$

Under these assumptions, the conventional national accounts give the correct net national product measure.

2. 2. Environmental resources

Let us now consider a more complicated case.

The economy is described by capital accumulation

$$K_{t+1} - K_t = f(K_{t+1}, Q_t, R_t) - C_t$$

where K_t is as before the stock of real capital in the beginning of period t . Q is the emissions from production and R_t is the use of a resource- S . The resource is governed by the following difference equation:

$$S_{t+1} - S_t = g(S_t) - R_t$$

Here $g(S_t)$ is the growth function of the resource. In case of a non-renewable resource, g is identically equal to zero.

Utility or welfare in time period t is a function of C_t , as well as of Q_t and S_t :

$$V = \sum_0^{\infty} U(C_t, Z_t, S_t)/(1+r)^t$$

Here Z_t is the environmental impact on the individual. The effect is determined first of all by the environmental disturbance Q_t . However, the individual is assumed to be able to modify this disturbance by defensive expenditures D_t . Thus

$$Z_t = h(Q_t, D_t).$$

The main balancing condition is that the total output is used for consumption, gross investment and defensive expenditures. Thus

$$C_t + K_{t+1} - K_t + Z_t = f(K_t, Q_t, R_t).$$

As before, we will study a "small project" (dC_t, dQ_t, dR_t) to find the first order effect on V from such a project.

$$dV = \sum_0^{\infty} \{U_c dC_t + U_z dZ_t + U_s dS_t\} / (1+r)^t.$$

However,

$$dC_t = f_K dK_t + f_Q dQ_t + f_R dR_t + dK_t - dK_{t+1}$$

$$dZ_t = h_Q dQ_t + h_D dD_t$$

$$dS_t = g' dS_{t-1} - dR_{t-1} + dS_{t-1}.$$

Let as before use the following notation for imputed prices:

$$p_t = \frac{U_{c_t}}{(1+r)^t U_{c_t}}, \quad q_t = \frac{U_z h_{Q_t}}{(1+r)^t U_{c_t}},$$

$$s_t = \frac{U_{s_t}}{(1+r)^t U_{c_t}}, \quad b_t = \frac{\bar{U}_z h_{D_t}}{(1+r)^t U_{c_t}}.$$

Substitution and rearranging yields

$$dNNP = \frac{dV}{U_{c_t}} = dC_0 - q_0 dQ_0 + b_0 dD_0 + dI_0$$

$$+ \sum_1^{\infty} [p_{t-1} f_{K_{t-1}} + p_{t-1} - p_t] dK_t$$

$$+ \sum_1^{\infty} [e_t dR_t]$$

$$+ \sum_1^{\infty} [s_t dS_t]$$

The first line represents the contribution to current well-being from a perturbation. dC_0 corresponds to consumption as it is usually compiled in the national accounts. The third term in the first line represents

the defensive expenditures and they are accounted for in present accounts. If the individual is free to choose defensive expenditures, it is obvious that $b_0 = 1$. What is not accounted for is the deduction of current environmental damage - $q_0 dQ_0$. Note that q_b represents the present willingness to pay for an improved environment and not the hypothetical willingness to pay in an optimum. If the individual can compensate a degradation of the environment completely by defensive expenditures, then these expenditures can be used as an approximation of the damage, and the two terms would cancel. However, this does not seem to be a general rule. The basic conclusion is that defensive expenditures should not be deducted.

The second line is the same as we have derived before. It indicates the inefficiencies in capital formation. As was noted above, it seems reasonable to neglect this term because the markets will probably come up with a better approximation of the future value of a unit of capital than accountant could do.

The third line represents the future cost due to present depletion of the resource. If we can assume that e_t is approximately constant over time and equal to e , then this term is simply $-dR_0$. If that assumption is not valid, then we can always write

$$\sum_1^{\infty} e_t dR_t - m_0 dR_0$$

where m_0 is the appropriate shadowprice on the production of the resource. If we would have been following an optimal path, the shadow price would have been equal to the value of the marginal productivity of the resource, i.e. $p_0 f_{R_0}$. On the other hand, if we assume that the resource is exhaustible (that is $g = 0$) and that the future changes in production of the resource will last for a specified number of periods and will be allocated in such a way that the corresponding change in the value of the production is constant, we would be able to derive the El Sarafy rule. El Sarafy, an economist at the World Bank calculated the Hicksian or Lindahl income from producing from an exhaustible resource under the assumption that the asset would be exhausted during a specified number of years and that the revenues generated would be the same in each year. The rule is obviously based on very arbitrary assumptions. In spite of that, one very often finds references to it. For example, in the studies by the UN and the World Bank which I referred to yesterday, use was made of the El Sarafy rule. As the output of the resource is sold on markets, it seems possible to use the same argument that I used for capital, namely that the current price on the resource also represents the expected future value of the resource. This implies that we could approximate the sum on the third line by $-p_0 dR_0 = n_0$ (where n_0 is the market price for the resource).

Finally, the last line represent the effect of a change in the stock of the resource on well-being. In order to calculate the shadow price, one needs an idea of how the future stocks will develop. Unfortunately, we can no longer rely on markets to solve the problem for us as there are no markets for these stock effects. We need to estimate the shadow price on a marginal change in the resource stock and that shadow price will obviously depend on the future development of the stock. If we are naive and believe that governments will introduce optimal management schemes, then we could once again rely on information on the current marginal willingness to pay for the stock. Another, perhaps more reasonable assumption would be to assume that the marginal willingness to pay for the stock will remain constant over the foreseeable future. This would enable us to calculate the shadow price by computing the present value of the infinite stream of this constant marginal willingness to pay for the stock.

Based on this discussion one would conjecture that the following formulation would give a not too bad approximation:

$$dNNP = dC_0 + b_0 dD_0 + dI_0 - n_0 dR_0 - q_0 dQ_0 - a_0 d\bar{R}_0$$

The first line represent terms for which there are market prices, while the second line represent terms for which shadow prices must be estimated. Of these, the first shadow price - q_0 - seems to be easiest as it does not involve any intertemporal considerations. The second shadow price is the present value of the future marginal values of the stock.

As I see it, the estimation of these shadow prices are the real problems when one wants to extend the accounting framework so as to include non marketed goods. The most popular method for valuing such goods - contingent valuation - has its own problems and is not universally accepted by economists as a valid instrument for valuation. Furthermore, applying contingent valuation is extremely expensive, and it would not be possible to use the method on a routine basis when data for the national accounts are processed. The only possible route, as far as I can see, is to use a revealed preference approach, where the preferences are mainly the ones revealed by political decisions in much the same vain as we now include public expenditures in the accounts. I believe that research in the future, both with regard to valuation of non marketed goods and with regard to extending the national accounts must be much more focussed on revealed preferences approaches in order to be really valuable for these rather down to earth problems I have been discussing.

2.3. Sustainability once again

Along the optimal paths, I showed that the Hamiltonian had some interesting properties. Basically, the Hamiltonian is the maximum well-being society can afford to day without depriving future generations their well-being. Is it possible to prove the a similar theorem when we are off the optimal trajectory? Obviously, we cannot prove the same theorem, but my conjecture is that the discrete Hamiltonian represents the maximum well-being - given the imperfections in the economy - society can afford to day in order not to deprive future generations of their well-being. I have not been able to prove that conjecture yet, but a number of small studies has made me believe that it is true.

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