A Proposed Approach to Environment and Sustainable Development Indicators Based on Capital

Robert Smith and Claude Simard[1]
Environment Accounts and Statistics Division
Statistics Canada

Prepared for[2]

The Canadian Economics Association Meeting
May 31 – June 3, 2001
McGill University

[1] The authors benefited greatly from discussions with colleagues at Statistics Canada (in particular, Alice Born, Craig Gaston, Gerry Gravel, Anik Lacroix and Doug Trant). Any errors remain their responsibility.

[2] This document was originally prepared for the Environment and Sustainable Development Indicators Initiative of the National Round Table on the Environment and the Economy. This version is slightly modified from the original (which was co-authored with Mr. Andrew Sharpe of the Centre for the Study of Living Standards) to shorten the discussion of human capital. The authors thank the National Round Table on the Environment and the Economy for permission to present this work at the Canadian Economics Association Meeting.

A. Introduction

1. This paper has been prepared for the National Round Table on the Environment and the Economy (NRTEE)'s Environment and Sustainable Development Indicators (ESDI) Initiative.[1,2] The authors were asked to provide a conceptual framework for the establishment of sustainable development indicators centred on the concept of capital and focused on the economy as the object of sustainability.[3]

B. Why a Capital Approach?

2. Capital comprises, by definition, those inputs that are necessary in economic processes and that endure (as opposed to inputs that are used up upon consumption). It is, in other words, what we pass on today so that the economy may continue tomorrow. As a concept, capital aligns very well with the temporal aspect of sustainable development. The essence of sustainability (as defined within the context of the ESDI Initiative) is that we wish economic production to continue for the benefit of the future (not because production is inherently good but because it contributes to human welfare). To do this, we need to maintain the means of production—or capital—intact over time. Capital embodies much of what is necessary to create the flows of services and materials necessary for economic production, today and for the future. If capital is maintained constant or growing over time, then economic production, too, can be sustained over time.

3. The argument that capital is necessary for the sustainability of production is based in economic theory with which most people will be unfamiliar. Even if unfamiliar with the theoretical notion of capital, however, they will have an intuitive sense of its importance. They know that they must maintain their homes, their belongings, their finances and, indeed, their bodies if these things are to continue to provide them with the security, income and health that are essential to a good life. Likewise, if presented with the notion that we as a nation must maintain those things needed to ensure the continuity of our economic system, most people would grasp the importance of doing so intuitively even if they would not equate it with the abstract notion of maintaining capital. Similarly, they would understand what the Minister of Finance meant if he rose in the House of Commons to report that economic

---

[1] The views expressed here should not be taken as reflecting the official views of Statistics Canada.

[2] In the time available to prepare this paper it proved impossible to enter into detail with respect to all of the concepts and arguments underlying the capital approach. The reader will note therefore areas in which essential points have been glossed over or not touched upon at all. Moreover, many of the arguments presented, particularly those with respect to the measurement of ecosystems, are still taking shape in the authors' minds and are not fully articulated here. It is hoped that these deficiencies are not so profound as to render the overall argument incoherent.

[3] This is, of course, not the only possible choice of object for sustainability. An alternative choice could have been to focus on the sustainability of human development (both social and economic) in general. A third possible choice—drawn from the "three pillar" approach to sustainable development—could have been to focus on the sustainability of the environmental system, the economic system and the social system concurrently. The implications of the latter two choices are not explored in this paper. It is worth noting that the choice of human development as the object of sustainability would not result in conclusions that are dramatically different from those presented in this paper. The adoption of the three-pillar approach would, on the other hand, lead to a substantially different set of conclusions.

output increased last year, but partly at the expense of degrading or losing some of what is necessary to ensure our ability to produce the same (or more) in the future. They would know that we were living the good life today at the expense of the future.

C. What Is Required for Economic Sustainability?

4. It is assumed here that economic sustainability means creating the conditions that are necessary to allow economic production to continue into the indefinite future. This does not mean that today's economy is to continue unchanged in structure and output forever. Rather, it means that we guard the possibility of arranging economic activity in whatever way will suit our future needs; that is, choices made today should not prevent future generations from making their own choices.[4] A static economy is undesirable because the elements of what is considered a good life have changed dramatically over time and will undoubtedly continue to do so. Our legacy to future generations should therefore not be economic stasis, but the passing along undiminished—and hopefully enhanced—of the means of economic production (i.e., capital) that we inherited. This will allow future generations to tackle the challenge of offering their version of a good life to as many people as possible.

5. Economic production in the strict sense of the term refers only to production that occurs in the context of market activity. This is (with some small exceptions) measured as the output of businesses and individuals operating for profit, plus the value of government services. The non-market activities of households or volunteers (cooking, child rearing, etc.) are not included as production in this sense. This is too restricted a view in the context of sustainable development, since much valued (in the psychological and not the monetary sense) activity takes place outside the formal market. From this point on, then, when we speak of production in this paper it should be interpreted as meaning the production of goods and services both within and outside the market.

6. In the mainstream of modern economic thought, economic production is defined as being a function of four "primary" inputs or factors: labour, produced capital (machinery and other durable goods), natural resources and land.[5] The first two combine with the last two to produce valuable products, which are then consumed (either to make other products or to satisfy the demands of final consumers). It is argued below that when this model of production (or production function) is interpreted from a capital perspective, it can serve as a very useful basis for defining sustainable development indicators. First, though, each of the primary factors of production is discussed in more detail.

---

[4] Note that the definition of the economy adopted here is strict. It says nothing about the welfare implications of economic activity (e.g., income distribution, labour practices or regional disparities). This focus on the sustainability of economic production has been adopted in order to restrict the range of variables to be measured to a manageable number and to avoid as much as possible the need to enter into debates on ethical principles. The latter, although clearly of great importance, are outside the proper domain of sustainable development indicators.

[5] See, for example, P. Samuelson, W. Nordhaus and J. McCallum, *Economics,* Sixth Canadian Edition (Toronto: McGraw-Hill Ryerson, 1988), p. 22.

C.1. Produced Capital

7. Economists define *produced capital*[6] as produced goods that provide benefits to their owners over time (as opposed to goods that provide one-time benefits such as a food). The benefits provided by produced capital goods are the services they render in the production of other goods and services. For example, a lathe provides a service over its lifespan that is the turning of wood in a particular fashion that allows the production of a variety of useful wooden products.

8. Economists have long recognized two fundamental features of produced capital. First, it is recognized that the extent of the produced capital service flows available within an economy is a direct function of the size of the total produced capital stock in the economy. Since production is a positive function of produced capital services, and more production is assumed better than less, the greater the size of the produced capital stock in an economy, the better, other things being equal. Second, it is recognized that produced capital deteriorates over time and must eventually be replaced if the economy is to be sustainable. This leads to the notion that some amount of total (or gross) income must be set aside during each period for investment in new capital to replace that which has worn out during the period. The income left over is net income, which is available for current consumption.

C.2. Labour

9. As with produced capital, considerable attention has been paid by economists to labour as a factor of production as well. A good deal of this attention has been paid in trying to determine the factors that determine productivity, or the amount of output per unit of input. One of the factors identified as playing a key role in overall productivity is the productivity of the workforce; that is, the quantity of goods and services produced per unit of labour input. This has led to the emergence of the concept of *human capital*, which can be thought of as the labour analogue to produced capital. Human capital is defined generally as the stock of educated and experienced workers available in an economy; it is the stock from which the flow of labour comes. The theory goes that a workforce with greater levels of experience and education will be more productive than one with lower levels. This is so for two reasons. First, better educated and more experienced workers presumably design and produce better forms of produced capital; this is what we call technological advancement. Second, better educated and more experienced workers presumably make more efficient use of the other forms of capital with which they work. The more human capital available in an economy the greater the value of its the services rendered by its workers (*i.e.*, labour).

10. 10. As with produced capital, it is recognized that human capital is susceptible to deterioration over time. This is partly because workers retire and have to be replaced, but also because knowledge and experience can become obsolete as new technology is introduced. Therefore, continual investment in the factors that contribute to human capital is required if the economy is to be sustainable.

11. 11. There is also the possibility that human capital will deteriorate because of reductions in the health status of workers. There is an obvious link here with the state of the environment to the extent that human health is at risk from environmental deterioration. This linkage

---

[6] Synonyms for produced capital include manufactured capital and physical capital.

should be explored as part of the development of indicators of sustainable development, but it is not touched up further here.

C.3. Natural Resources

12. Of the four primary inputs to production, economists have paid least attention of all to natural resources. The old view of nature as an all-but-limitless source of costless resources has meant that economists have invested relatively less effort in the study of natural resources than of inputs to production that have always been scarce.[7] Since there is no "price" charged by nature for the use of these resources, less is gained by studying them in an effort to reduce overall production costs and thereby maximize profits. That natural resources enter the production function at all is simply due to the labour and produced capital costs associated with their discovery and their extraction.

13. While natural resources merit recognition in the production function because of their associated discovery and extraction costs, other uses of the environment for which there is no cost at all are left completely out. For example, the free use of the environment as a sink for waste materials does not figure in the production function even though production clearly depends on the availability of this service. Without this service (and many others provided at zero direct cost by the environment), producers would be forced to find other, more costly means of dealing with their wastes. Of course, in that case wastes would represent direct costs to producers and enter the production function.

14. The refusal to recognize essential but unpriced inputs in the production function is defensible only when current profit maximization is the sole concern. In the case of this paper, where the question of ensuring the sustainability of production is primary, it is clear that a broader view of the factors of production is needed. The view of nature as infinitely rich may have been legitimate in the relatively empty world of the 19th century, when the scale of resource use was negligible compared with resource stocks. It is certainly no longer valid in a relatively full world where resource consumption is on such a scale that entire stocks of some resources have been wiped out through human activity.

15. In the last decade a school of thought has emerged in which the environment is seen as comprising a variety of forms of capital that are just as important to the sustainability of the economy as are produced and human capital.[8] These newly recognized forms of capital, which have come to be called collectively *natural capital*, are the source of the priced and unpriced environmental inputs upon which economic production depends. It is now increasingly recognized that natural capital must be maintained over time along with produced and human capital if the economy is to be sustainable.

---

[7] This is not to say that there is not a long-standing school of thought related to the importance of natural resources in economic activity, for there certainly is. It is simply a reflection of the fact that a great deal more attention has been paid by economists to the other two factors of production.

[8] The most complete exposition of this thinking is that of David Pearce and his colleagues at University College in London. See, for example, D.W. Pearce and R.K. Turner, *Economics of Natural Resources and the Environment* (Baltimore: The Johns Hopkins University Press, 1990).

D. What Is Natural Capital?

16. Natural capital is generally considered to be divided into three principal categories: natural resource stocks, land and environmental systems (or ecosystems). All are considered essential to the long-term sustainability of the economy. Natural resource stocks are the source of raw materials used in the production of manufactured goods.[9] Land is essential for the provision of space in which economic activity can take place.[10] Ecosystems are essential for the services that they provide directly and indirectly to the economy, including cleansing of fouled air and water; provision of productive soil; provision of biodiversity; provision of a predictable and relatively stable climate; protection from incident solar radiation; and provision of reliable flows of renewable natural resources.[11]

17. The long-term sustainability of the economy is seen by adherents of the natural capital school as depending upon the maintenance of natural capital just as much as it depends on stocks of produced and human capital. If stocks of natural resources decline to the point where they are no longer able to provide sufficient raw material inputs to support the needs of economic production, it is obvious that production of that level and type is no longer sustainable. Likewise, if the natural functioning of ecosystems is disrupted by human activities to such a point that the quality of the services they provide (and upon which economic production depends) declines, then that level and type of economic production is no longer sustainable. Of course, this is not to say that *some* level and type of economic production is no longer possible, only that changes will have to be made to either 1) eliminate the need for a particular natural capital service or 2) find a means of replacing the natural capital service with a service of produced capital.[12] The need to "maintain" stocks of land is slightly more complicated, as land is (for all practical purposes) neither created nor destroyed. However, land of a particular type (e.g., good quality agricultural land) can be exchanged for land of another type (e.g., urban land). To the extent that the economy relies on the availability of adequate areas of specific land types, it is possible that long-term economic sustainability

---

[9] As noted above, raw materials have always been recognized (at least when priced) as factors of production. The natural capital school simply recognizes that if raw materials (priced or unpriced) are essential to production in the current period, then their sources must be essential to production in the long term.

[10] Land, too, has always been recognized as a factor of production, although it is not recognized in mainstream economics as a category of capital. The natural capital school suggests that land is a form of capital whose input to economic activity is, literally, the space in which the activity takes place.

[11] Note that there is a circularity here. Ecosystems are essential in part for their provision of steady flows of renewable resources, and renewable resources are essential as sources of raw materials for economic production. It would be wrong to suggest that both the service of the provision of renewable resources *and* the resources themselves must be measured to assess sustainability. Since the former is much more difficult than the latter to measure, the focus for measurement should be on the resources and not this particular function of ecosystems. This point will be returned to later in the paper.

[12] Sewage treatment plants are a good example of the latter. Because our sewage production far exceeds that which our rivers could accept without suffering a dramatic decrease in their level of functioning, we have been forced as a society to divert financial and human resources away from other (presumably welfare enhancing) purposes into the production and operation of sewage treatment plants. These plants do nothing more than replace the waste assimilation service that the natural capital (the river) cannot provide at that level of sewage production.

may be threatened by changes in land use patterns.[13]

18. Like produced and human capital, natural capital is subject to deterioration from economic use. This deterioration comes either in the form of quantitative depletion or qualitative degradation. The former is associated mainly with the extraction of natural resources as raw materials for use in the economy. In the case of non-renewable resources (metals, minerals, fossil fuels), this extraction represents a permanent drawing down of the earth's store of these finite resources. In some cases, the stocks of these resources are extremely large (as with sand and gravel), although still finite, and our use of them represents no real threat to the long-term sustainability of economic activity. In other cases, stocks are relatively smaller (as with natural gas) and long-term sustainability may be at risk if substitutes[14] cannot be found for the resources in question. In the case of renewable resources (timber, fish, water[15] and other flora and fauna), economic use need not lead to quantitative depletion, but will do so if extraction exceeds natural growth. As we know, this is too often the case.

19. Qualitative degradation of natural capital results from excessive use of its services. Excessive use implies use beyond that which the environment can support without any measurable change in the functioning of ecosystems. Excessive use of natural capital can be the result of harvests of renewable natural resources that exceed the capacity of ecosystems to provide these resources. Equally, it can result from waste loadings on the environment that exceed the assimilative capacity of the environment.

20. In the case of either quantitative depletion or qualitative degradation of natural capital, there is the possibility that economic production will be rendered unsustainable, if not today then at some point in the future.

E. Summary of Capital and Its Relation to Sustainability

21. The last two sections on capital and its relation to economic sustainability can be summarized as follows. Current economic production is reliant upon three key factors: labour, produced capital and environmental inputs (raw materials, land areas and ecosystem services). Each of the primary factors is in turn a function of a capital stock. Labour is a function of human capital, and environmental inputs are functions of natural capital (produced capital being already explicit in the production function). The stock of each type of capital available today is what determines the possibilities for production in the future. Produced capital and human capital have traditionally been accounted for as determinants of production possibilities. With the exception of selected natural resources and land areas (those that bear prices), natural

---

[13] For example, good quality agricultural land supply in Canada has been slowly declining since the beginning of urbanization as cities and towns expand onto surrounding farmland. Sometime in the early 1980s, it is estimated that the area cultivated for crops actually exceeded the supply of good quality land. We are now into a situation where future expansion of farmland will have to occur on marginal land (Statistics Canada, *Econnections—Linking the Environment and the Economy: Indicators and Detailed Statistics*, Cat. No. 16-200-XKE [Ottawa, 1997]).

[14] See the section below on the possibilities for substitution for a more detailed discussion on this point.

[15] Groundwater in slowly replenishing aquifers can be considered for all intents and purposes a non-renewable resource.

capital has only in the last decade, and only by relatively few economists, been recognized as a determinant of economic production.

22. All forms of capital are subject to deterioration over time and must be maintained if production is to be sustainable. In the cases of produced and human capital, capital maintenance requires investments in replacement of worn-out machinery, equipment, and so forth, and in the ongoing education of workers. In the case of natural capital, capital maintenance implies the need to restrict the use of natural capital within the limits of the environment to provide it.

23. As a conceptual basis for the development of sustainable development indicators, the capital approach suggests the need to measure stocks of each form of capital and their evolution over time. In the case of natural capital, it also implies the need to measure the demand for the environmental services to determine whether demand exceeds the capacity of ecosystems to supply them. This suggests an expansion of the traditional production function to include all forms of natural capital (not just natural resources) and to include the disbenefits of economic production (e.g., wastes) that can lead to deterioration in the functioning of ecosystems. The indicators of sustainable development that are suggested at the end of this paper reflect this new interpretation of the economic production function.

F. The Measurement of Capital

24. If, as has been argued to this point, the sustainability of economic production relies upon the maintenance of the three basic types of capital—produced, human and natural—there is a compelling reason to measure carefully the current state of each type and its evolution over time when assessing sustainability. In this section we talk about how capital is currently measured, how it could be measured where it is not already, and how these measures might be incorporated into indicators of sustainable development.

F.1. Produced Capital

25. As noted above, economists have long paid attention to the measurement of produced capital. Nearly from the beginning of modern economic theory it was recognized that production relied upon the availability of produced capital and, therefore, economists set out very early to measure it. Today, estimates of produced capital are produced on an annual basis by Statistics Canada in the National Balance Sheet Accounts of the System of National Accounts. While these estimates are not without their flaws, they represent much of what an ideal measure of produced capital for Canada would be. As these measures are adequately documented elsewhere, they will not be described any further here. The NRTEE may wish to commission a paper devoted to a fuller assessment of these estimates as the basis for sustainable development indicators.

F.2. Human Capital

26. As noted above, it is only in recent decades with the study of productivity that the notion of human capital has come to the forefront in economics.16 Due in part to the relative youth of

---

[16]It is important to bear in mind the distinction between human capital and labour. Human capital comprises the stock of educated and experienced workers in the economy and labour is the output of this stock. Of course, labour

the notion, there exist no official estimates of human capital in Canada (or any other country for that matter) at this time. Nonetheless, a growing body of academic research exists on the subject and it is currently being studied seriously by governments.17 It can be safely assumed that measures of human capital will evolve independently of the development of indicators of sustainable development and that, therefore, the SDII can "piggy-back" somewhat on the work currently underway elsewhere. The Steering Committee will undoubtedly want to find a means to inform itself of the state of development of this work, a task that is beyond the scope of the present note.

F.3. Natural Capital

27. The measurement of natural capital is by no means straightforward. Nor has it to date benefited from much conceptual or empirical research. For these reasons, the suggestions presented in this section should be taken as starting points for discussion rather than as fully developed concepts.

28. To begin with, it is useful to recall the major categories of natural capital mentioned above: natural resources, land and ecosystems. The greatest measurement challenge presents itself with respect to the third of these, so let us begin with the easier two first.

F.3.1. Natural Resource Stocks

29. When we think of natural resources as capital, we are really thinking of stocks of natural resources as they exist in the environment: deposits of fossil fuels and minerals under the ground; tracts of timber standing in forests; stocks of fish swimming in lakes or oceans; water in underground aquifers or flowing on the surface; and wild flora and fauna in their natural habitats. In principle, measuring these resources in natural capital terms means estimating the quantity and/or quality of these resources found within Canada's borders in physical and/or monetary terms.

30. An appropriate physical measure can be hypothesized for any type of natural resource. Actually applying this measure to observed stocks of resources is not always straightforward, not least so because we are uncertain of the existence of many natural resources (particularly those underground) but also because we cannot actually undertake to observe our entire stock of certain resources (timber, for example) at one time due their vastness.

31. While physical measurement applies in theory to any natural resource stock, the same is not true for monetary measurement. Only those natural resources that are traded in the market

---

has been studied by economists since the beginning of their science. The explicit study of human capital as the stock from which labour flows is, however, more recent.

[17]See, for example, Jorgenson, Dale W. and Barbara M. Fraumeni, 1989, "The Accumulation of Human and Non-human Capital", 1948-1984, in ***The Measurement of Saving, Investment, and Wealth***, ed. R.E. Lipsey and H.S. Tice, (Chicago: University of Chicago Press) and Laroche, M., Merette, M. and Ruggeri, G.C., 1998, *On the Concept and Dimensions of Human Capital in a Knowledge-Based Economy Context*, http://www.fin.gc.ca/activity/wp-dt/98-01e.pdf.

lend themselves in a straightforward manner to stock measurement in monetary terms (and even then there exist severe empirical restraints on what can be measured). Natural resources that are not traded in the market, such as groundwater and most flora and fauna, are both conceptually and empirically challenging to measure in monetary terms. A further complication arises from the fact that the value of natural resources is to some extent bound up in the value of the produced and human capital that is employed in their exploitation. Separation of these values is not always possible. For these reasons, it may be best to stop at physical measurement for some natural resources. Note that this should not be taken to imply that these resources play no role in economic well-being, for they certainly do, for example, in contributing to recreational experiences.

F.3.2. Land

32. Much like natural resources, the measurement of land as capital implies evaluating the physical extent of land of various types and placing a monetary value on it when possible and desirable. Since land is fixed in total extent, changes in the physical extent of one type of land must be offset by changes in the opposite direction in another type of land. For example, if urban areas are increased, this can only be done at the expense of reductions in the area of land used for other purposes.

33. Physical measurement of land is usually done by considering land from the perspective of either its cover or its use. Evaluating land from the perspective of cover is generally more straightforward than evaluating its use. The same parcel of land may have multiple uses (e.g., timber production, recreational area and wildlife habitat), but it will have only one cover type (e.g., mixed forest).

34. Direct monetary valuation of land is possible in relatively limited instances. Only when land parcels are bought and sold in the market (e.g., built-up land, agricultural land) can land values be directly established. In the case of land that is not transacted, indirect methods of valuation do exist but are subject to conceptual and empirical constraints. The value of land that is not used as a direct input into production activity is related to the value of the ecosystem services that the land supports. Moreover, separating the two values may be impossible. For these land areas, physical measurement may be all that is possible.

35. The contribution of land to sustainability is related to its direct use as a source of space for economic activity (urban land, other built-up land and agricultural land) and to its indirect use as the space in which terrestrial ecosystems operate. As just noted, the latter use is difficult if not impossible to separate from the evaluation of the ecosystems themselves, which is the subject of the discussion immediately below. With respect to the direct use of land, the clearest threat to sustainability in Canada comes from the supply of agricultural land (there being little risk of not having enough land for expansion of built-up areas). Agricultural land is threatened in two ways: conversion of agricultural land to other purposes and degradation of the quality of agricultural land from excessive use. Clearly, there is need for an indicator of sustainable development focused on this aspect of land use.

F.3.3. Ecosystems

36. Of the three dimensions of the environment, ecosystems are the most difficult to measure as capital. In theory, the correct approach is to observe the services that are provided by ecosystems to the economy and to estimate the value that these services represent as

contributions to production. In practice, even if we can define what these services are, we cannot observe them directly, just as we cannot observe the transportation service that an automobile provides us. In the latter case, economic theory has found a means of assessing the value of the automobile as capital even if it is not possible to observe the services it provides directly. The theory says that the present value of the services that will be rendered by the automobile over the extent of its life is exactly equal to the price established for it in transactions between buyers and sellers in a free market. The argument behind this notion is that no rational purchaser would be willing to pay more for the automobile today than the value he or she could expect to obtain through the use of it over its life. While this theory may be useful in establishing the value of produced capital goods that are commonly bought and sold, it is of no use at all in establishing the value of ecosystems. Another approach must be found to evaluate ecosystems.

37. If it is not possible to observe the services offered by ecosystems and no market in these systems exists that would establish a value for their services, then the next best thing is to evaluate ecosystems based on the quality of their outcomes. Earlier in this paper, a list was given of some of the major services provided by ecosystems: cleansing of fouled air and water; provision of productive soil; provision of biodiversity; provision of a predictable and relatively stable climate; protection from incident solar radiation; and provision of reliable flows of renewable natural resources. This list translates naturally into a list of outcomes that are more or less observable and that could be used as the basis for evaluating the state of natural capital. If the outcomes of ecosystem services are constant over time (e.g., air quality is non-declining) then one can conclude that the natural capital—that is, the ecosystems—that operate to provide the services that lead to these outcomes are being maintained. This argument leads to the conclusion that ecosystems are best evaluated in physical and not monetary terms. The evaluation of air quality and other ecosystem outcomes is inherently a question of physical measurement. This in turn leads to the conclusion that individual indicators will be required for each of the major functions of ecosystems (unless a meaningful method of aggregating such physical measures can be found).

38. Obviously, the measurement of ecosystem service outcomes is by no means straightforward. Nevertheless, it is argued here that this is the conceptually correct means of evaluating ecosystems as natural capital and it is the one that offers the most promise for empirical implementation. A great deal more thinking is, of course, required before the notion can be translated into working indicators of sustainable development; the purpose of this paper is merely to suggest this approach as a starting point for discussion. Some very preliminary thoughts on how measures of ecosystem service outcomes might be incorporated into sustainable development indicators are offered below in Section I on indicators.

G. To What Extent Is Capital Substitutable?

39. To this point, it has been argued that produced capital, human capital and natural capital are all essential in ensuring the sustainability of the economy. Thus measures of all three will have to figure somehow in indicators of sustainable development. A fundamental question then is whether separate indicators are required for each category, or whether indicators that combine the three are possible. To answer this question, it is necessary to address the possibility for the substitution of capital.

40. Substitution of capital refers to the use of one form of capital in place of another in a

production process. For example, in years gone by, statistics were tabulated manually by rows and rows of clerks transcribing information from completed survey questionnaires into ledgers (a clear use of human capital). Today, this same function is performed largely by computers (produced capital). To economists, this represents an example of substitution; the same output is produced using a different combination of capital inputs. In this case, produced capital has substituted for human capital.

41. Now, if the possibilities for using one form of capital in place of any other form of capital are limitless (i.e., there is perfect substitutability) then there is no reason to measure the various forms of capital independently. Economic sustainability is ensured as long as aggregate capital stocks are not declining over time. It is not, of course, necessarily or even probably the case that the possibilities for substitution are limitless for all forms of capital, however. Many forms of capital are of value only when combined with another form. For example, a fishing fleet (produced capital) is essentially worthless unless combined with healthy fish stocks (natural capital) to exploit. In this case, the fishing fleet and the fish stocks are said to be complementary. But this is just a limited example of complementarity, where a subset of one type of capital is complementary with a subset of another type of capital. There is another possibility as well. This is that a certain form of capital provides a service that is essential to the functioning of the entire economic system and for which there exists no known substitute. Although examples of this type of capital are few (and there may be no absolute example), global atmospheric systems that provide the services of protection from solar radiation and climate regulation come very close.

42. One cannot avoid the question of time horizon when speaking of the substitutability of capital. The classification of a particular type of capital as substitutable or complementary depends at least to some extent upon the period over which the possibilities are considered. Examples of complementarity are much more frequent when a short time horizon is taken.[18] In the above case of the fishing fleet, for example, loss of a fish stock certainly creates problems of sustainability in the short term, since fishers cannot be retrained instantly and the capital bound up in fishing boats cannot be liquidated instantly. Over time, however, at least some of the human and produced capital devoted to fishing may be redirected to other pursuits, and economic production will recover to some extent. The question of what is the appropriate time horizon when considering the substitutability of various forms of capital is not one that can be answered here, but it does deserve further attention.

43. Questions of time horizon aside, the position taken in this paper is that overall there are significant possibilities for the substitution of some types of natural capital and limited or no possibilities for the substitution for other types.[19] There is a very high degree of substitutability for some types of natural resources (minerals, metals and fuels) and essentially no substitutability for global systems like the atmosphere. That substitution of

---

[18] Taking a short time horizon when considering sustainable development will increase the frequency of complementarity mainly at a local or sectoral level. The fact that fishers in some villages are out of work because of the loss of natural capital does not imply that the overall economy is unsustainable.

[19] The possibilities for substitution between produced and human capital are not discussed here.

natural resources is possible is demonstrated clearly by the many instances in which human ingenuity has arrived at means of making better use of (or even eliminating the need for) certain natural resources through new technology. A simple example is the sawmill. Timber is used much more efficiently if it is cut with a blade than with an axe, and so sawmills allow more production from the same amount of wood.[20] In other instances, technology has allowed substitution of a relatively rare form of natural capital with one that is superabundant. For example, fibre optic cable has replaced much of the copper that used to be required for communications lines. Of course, there is no certainty that the past will be a reliable guide to the future, but the historical record to date does give some reason to believe that we will continue to find means of substituting certain natural resources (metals, minerals, timber, water and fossil fuels) with produced or human capital. This is not meant to imply that there is no reason to account for stocks of these resources, but that the manner in which we account for them is different than it would be if they were irreplaceable.

44. At the other end of the substitution spectrum are examples of natural capital for which no substitute has been found or is likely to be found. As already mentioned, these are relatively few in number but extraordinarily important in contributing to economic production. The best examples are global atmospheric systems that control climate and regulate radiation reaching the earth. We know of no way of directly substituting for these systems (sunscreen is *not* a substitute for the ozone layer). If their functioning is reduced, the best we can do is hope to adapt to the changes.

45. In between the two extremes are examples of natural capital for which there may exist some opportunity for substitution but for which not all functions are substitutable. For example, even though we are able to substitute swimming pools (produced capital) for beaches that have become unswimmable, we are also aware that beaches serve other purposes than being pleasant settings for weekend fun. We do not fully understand all these other functions, however. Thus degrading beaches up to the point where it is necessary to substitute for them with swimming pools may be unwise even if it allows us to continue to swim in clean (if chlorinated) water. The unforeseen consequences of degrading beaches and then replacing their services with produced capital may return to haunt us in ways that are more costly than finding the means to prevent beaches from becoming polluted in the first place.

46. The above arguments lead to the conclusion that valid indicators of sustainable development can be constructed by combining different categories of capital only if substitution is a viable option. If substitution is impossible or if we are unaware of the consequences of degrading natural capital and then replacing it, prudence would require that we measure these types of natural capital independently in sustainable development indicators.

H. Physical Versus Monetary Measurement

47. In principle, it is possible to measure any form of capital using either physical or monetary units of measure. Produced capital can be measured in terms of number of machines of a specific type or in terms of the value of the services provided by the machines. Human

[20] Of course, the possibility for substitution of wood with sawmill technology is not limitless. Obviously, at some point wood and sawmills are fundamentally complementary. This serves to illustrate the point that substitution is often possible only within limited ranges.

capital can be measured in terms of years of education or in terms of the value of the labour services workers provide. Natural capital, too, can be measured in terms of the physical extent of resources and ecosystems or in terms of the value of the materials or services they provide. However, for various reasons, it may not always be appropriate to use one or the other form of valuation depending on the type of capital in question. The reasons for this are partly explained by considering the benefits and drawbacks of each type of valuation.

48. Monetary measurement offers one major advantage over physical measurement: the possibility of aggregating disparate forms of capital. Because monetary valuation uses the same set of weights (market prices) to value no matter what type of capital, the values arrived at are comparable and can be summed. For example, if we think of two machines that perform similar functions (let us say production of paper) but with greatly differing efficiencies, the price of the two machines will (in theory, anyway) capture this distinction. The more efficient machine will have a higher purchase price and therefore will represent a greater amount of capital. Arriving at a physical measure of the machines that adequately captures this quality difference is conceptually very difficult. This problem is multiplied manyfold when all the different machines performing all the different functions in an economy are considered; this is why produced capital is always measured using monetary values.

49. In addition to providing the possibility of aggregating within a given category of capital (e.g., summing the value of all machinery), monetary valuation also provides the possibility of comparing or aggregating across forms of capital. This becomes very important in instances where substitution of capital is a consideration. If it is accepted that produced capital can sometimes substitute for natural capital (as in the example of the sawmill above), then it is desirable that both forms of capital be measured using the same yardstick. In practice, the only common yardstick available is money. When both forms of capital are measured using monetary values, their evolution over time can be tracked to assess whether in aggregate they are being maintained (even if one or the other is declining in its share of the total). Sustainability in this case demands only that the aggregated capital stock be maintained, since production is indifferent to which type of capital is available.

50. Regarding human capital indicators, the monetary value of the average educational attainment of the working-age population (or labour force) can be estimated by the stream of future earnings of the population arising from that education and calculating the present value of this earnings stream with a discount rate. The monetary value of the literacy level of the working-age population (or labour force) is conceptually more difficult to calculate than the monetary value of human capital accumulated through formal education. If earning data are available for the various literacy levels, then the demand-side future earnings approach may be used.

51. It is difficult to place a total value on Health-Adjusted Life Expectancy (HALE) just as it is difficult to place a value on life. It is easier to put a value on changes in the HALE. By the use of contingent valuation techniques or other methodologies, one can value how much people would be willing to pay for an additional year of healthy living. Equally, these techniques can be used to value changes in self-reported health status.

52. Despite its advantages, monetary valuation is sometimes not appropriate for natural capital. In particular, it is not appropriate in cases where there exists no possibility for substitution. Natural capital that is essential for the overall functioning of the economic system is

effectively priceless and can only be sensibly evaluated using physical measures. The same is probably true for capital for which the possibilities for substitution are greatly restricted even if not zero. This is particularly true because the prices that are the heart of monetary valuation are established in markets that fail (in some cases dramatically) to internalize the environmental costs of economic activity. It is not sensible to use such prices to value the very services of natural capital that are effectively taken to have a zero price in the economic transactions that are the basis for establishing the prices.

53. It should also be mentioned that monetary valuation of the environment, even if technically possible, does not sit well with all people. Many feel that the inherent value of nature is sullied by bringing it within the fold of economic calculation, where only the bottom line of profit (for the benefit of humans) matters. This condemnation of monetary valuation is worth bearing in mind when establishing the indicators of sustainable development, as it may significantly influence their acceptability to certain audiences.

I. A Possible Core Set of Sustainable Development Indicators

54. Based on the arguments offered to this point, it is possible to suggest a potential set of sustainable development indicators based on the concept of capital.[21] The set offered below is restricted to high-level indicators related to what the authors perceive to be the most critical aspects of capital in sustaining the economy. It may well be that these "core" indicators should be accompanied by more specific indicators dealing with capital on a sectorally or spatially disaggregated level. Whether or not this is so is a topic for another paper.

55. Ideally, indicators of sustainable development based on the concept of capital should provide direct measures of the quantity and quality of capital available in Canada. Indicators of this sort are the "first order" choice. Not all capital lends itself to direct measurement, however. Ecosystems in particular are not observable in a quantitative sense and even evaluating them in a qualitative sense is not straightforward. A "second order" choice of indicator in these cases can be developed by considering the outcomes of the functioning of capital. Presumably, if the outcomes of capital functioning remain of constant quantity or quality over time, then one can conclude that the capital itself remains intact. A "third order" choice of indicator would look at the demand for capital services. While indicators of this sort say nothing about the actual quantity or quality of capital available, they do measure how the use of the capital evolves over time. Presumably, if the demand for capital is steadily increasing, eventually the point will be reached where it will outstrip the capacity of the capital to provide services. Indicators of all three of these types are suggested below.[22]

---

[21] In some instances, the indicators suggested here reflect very unrefined thinking, and the reader should expect to find logical and conceptual gaps and weaknesses. This is particularly true with respect to the indicators related to ecosystems. Obviously, the suggestions made are intended only as starting points for discussion, and it is fully recognized that a great deal more work is required before agreement will be reached on what is the most appropriate core set of indicators. Once this agreement is achieved, each of the proposed indicators in the set will be a candidate for a detailed research paper of its own.

[22] Note that the notion of first, second and third order indicators is not meant to imply an ordering of indicators in terms of importance in measuring sustainable development but only a logical ordering of indicators in terms of their adherence to the principles of the natural capital theory. Second and third order indicators may well be crucial indicators of sustainable development, even if they are not the ideal indicators from a theoretical perspective.

56. We must emphasize here the fundamental importance of supporting whatever set of sustainable development indicators are ultimately chosen with a detailed underlying information system, ideally in the form of a set of integrated accounts. This is an out-and-out necessity if the indicators are to enjoy any use beyond attracting headlines in newspapers. It is therefore important that the choice of indicators should include considerations of the information system that will underlie them.

I.1. Produced Capital

57. The suggested indicator of produced capital is simply the value of produced capital as currently measured by Statistics Canada in its National Balance Sheet Accounts. As this indicator exists already, no more space is devoted to it here. A discussion of it, including its conceptual weaknesses, can be provided at a later date if requested.

I.2. Human Capital

58. This would be an indicator of the value of Canada's human capital. The current literature on valuing human capital consistently includes education as an important component of human capital, so it is presumed that education would factor in this indicator as well. Other possible determinants of human capital include years of working experience and health. And as noted earlier, the relationship between human capital, health and the state of the environment is a matter that deserves further study as well. It is recommended that the Steering Committee commission a specific study into the current state of development of measures of human capital.

I.3. Natural Resource Wealth

59. An indicator of natural resource wealth would measure the value of Canada's commercial natural resource stocks—timber, marine resources, minerals, metals and fossil fuels. In valuing these stocks and aggregating them into a single indicator, we implicitly assume that none of these stocks is in and of itself crucial to the sustainability of the economy. That is, we assume a significant degree of substitutability among them, at least at the national level. Not all Canada's resource stocks would be valued for inclusion in the indicator. Only those stocks that are known to exist with a high degree of certainty and that can be profitably exploited under today's prices and technology would be valued. This restriction is necessary for meaningful monetary valuation, as the costs involved in extracting not-yet-discovered resources are unknown and cannot be assumed to be same as those for extracting known resources. It is also necessary to restrict the indicator in this way so that it is comparable with the estimates of produced capital and human capital.

I.4. Total National Wealth

60. This is an aggregation of the first three indicators. It represents an estimate of the total economic wealth of the nation, that is, the wealth represented by those forms of capital that provide the materials and services necessary to directly support market economic activity. The implicit assumption in aggregating across the three broad categories of capital is, as with indicator 3, that there are significant possibilities for substitution among these forms of

capital. Thus no one of them is in itself crucial to the sustainability of the economy. This is, of course, not true in the limit. The complete (or even significant) loss of one of the three broad categories would certainly render the economy unsustainable and even totally unviable. Thus the indicator is useful only when the relative changes in capital from one period to the next are at the margin.

61. The trend in this indicator provides the best measure of whether the overall market capital needed to provide the materials and services required by the economy is being maintained or not. If it is not, then other things being equal, the economy is not on a sustainable trajectory. Although it is assumed in this indicator that the individual components of market capital need not be maintained individually (because of substitution possibilities), the indicator would ideally be interpreted alongside the first three indicators to determine what sorts of trade-offs are being made among the various forms of capital in the economy.

I.5. Physical Quantities of Natural Resource Stocks

62. This indicator is a required complement to indicator 3 (natural resource wealth). It measures the physical extent of the natural resources that are presented in value terms in indicator 3. Unlike indicator 3, in which stock values for these resources were aggregated, in this indicator the resource stocks are presented individually.[23]

63. There are many different measures of natural resource stocks that could be proposed for this indicator. Certainly, there is a need for different measures with respect to renewable and non-renewable resources. In the case of renewable resources, sustainable use in a strict sense implies that annual harvesting not be greater than annual growth. Clearly, then, an appropriate indicator for renewable resources would present annual stock size, annual increment to the stock size and annual extraction. However, it is not evident *a priori* that a declining stock size for a given renewable resource is necessarily a sign of immediate unsustainability of the economy. Large portions of Canada's original timber tracts were harvested long ago and converted into farmland. This represented a substitution of one form of natural capital (forest land) by another form (agricultural land), and it clearly did not render the Canadian economy unsustainable. There is a significant difference between the demand for timber and agricultural products then and now, however. Agricultural land use in Canada (as mentioned earlier) has now outstripped the supply of good land. Likewise, timber harvesting takes place on the same order of magnitude as timber growth. Thus it can be argued that we have either passed (certainly in the case of some fish stocks) or are close to the point where our demand for renewable resources has outstripped the environment's capacity to supply them. Thus an indicator of the physical size of our renewable resources and their productivity vis-à-vis our exploitation of them would seem the appropriate sustainable development indicator.

I.6. Agricultural Land Use Supply and Demand

64. An indicator of agricultural land use supply and demand would measure the area of dependable agricultural land available in Canada and contrast this with the area of land

---

[23] Note that this introduces the possibility of many additional indicators if one is required for each resource. To avoid this, consideration should be given to developing a meaningful approach to aggregating the physical stocks. Additional research will be required to determine if this is feasible.

cultivated for crops. Dependable land is that which is generally free of severe constraints for the long-term cultivation of Canada's most common crops. It is, in other words, our good farmland. The area of land cultivated for crops is the sum of all areas actually used for crop production, whether dependable land or not.

65. This indicator would provide a dual measure of the long-term sustainability of agricultural activity. First, by contrasting the supply of dependable agricultural land with the area of land actually cultivated for crops, the indicator would portray the extent to which agricultural activity relies on marginal land. This is significant because marginal land is often unsuitable for stable, long-term agricultural production. Such land is, by definition, affected by severe constraints for crop production (poor soil texture, inadequate drainage and adverse slope, for example). Production on marginal land may also be more environmentally harmful, as these lands are often susceptible to soil damage resulting in erosion, and require greater inputs of fertilizers, pesticides and water to achieve a given yield. A sustainable agricultural system would, ideally, be one in which the area of land cultivated for crops coincided with the area of available dependable agricultural land.

66. Second, the indicator would demonstrate how the total supply of dependable agricultural land has diminished over time from conversion to urban and other purposes.[24] Loss of dependable land to other uses would be a key measure of the long-term sustainability of farming in Canada. Despite Canada's size, dependable agricultural land is a scarce resource in this country; less than 5% of our land is free from severe constraints for crop production.

I.7. Indicators of Ecosystem Service Outcomes

67. It is proposed that a group of indicators be included in the core set to cover the major ecosystem service outcomes essential for the sustainability of the economic system. These are examples of "second order" indicators, since they do not measure ecosystems directly but instead focus on the outcomes of the services that well-functioning ecosystems provide. The services in question have already been listed above: cleansing of fouled air and water; provision of productive soil; provision of biodiversity; provision of a predictable and relatively stable climate; protection from incident solar radiation; and provision of reliable flows of renewable natural resources. These services are essential for the sustainability of the economic system because, in one way or another, the current form of economic production relies on these services for its functioning, that is, these services are directly or indirectly used in economic production and if they were to disappear it would be necessary to alter production to do without them or (if possible) replace them.

68. It has been argued above that the conceptually correct means of evaluating ecosystem services is to consider the quality of their outcomes. Thus an indicator must be found for each ecosystem service that measures its outcome in a way that translates into a meaningful assessment of the state of functioning of that ecosystem. We do not pretend to have identified such an indicator for all of the ecosystem services listed above, or even to have fully worked out the details of any one indicator. This will require a great deal more thought and consultation with experts in relevant domains. What are offered below are merely some

[24] Aside from urban areas, other non-agricultural uses of dependable land include roadways, railroads, power lines, pipelines and parkland.

preliminary thoughts on what directions of research might prove fruitful.

I.7.1. Indicators of Air and Water Quality

69. Clean air and water are obviously two of the most important outcomes of ecosystem services. They are necessary both for the benefit of the humans who breathe and drink them and for the contribution they make to other ecosystem outcomes (e.g., assuring reliable supplies of renewable natural resources). The latter contribution should be captured implicitly in indicators measuring these other ecosystem outcomes, so it is only the former that need be considered directly in the indicators of air and water quality.

70. It is obvious that national indicators related to air and water quality are meaningless unless they somehow incorporate the exposure of the population to air and water of varying quality. The fact that the air quality is good in most parts of Canada is of very little comfort to those living in polluted urban areas and suffering from respiratory ailments. The approach that is suggested here is to develop indicators that present population-weighted aggregations of the exposure to air and water of varying quality over the course of a year. Thus one million people living in an area in with good water quality would weigh more heavily in an indicator than one thousand people living in an area with relatively poor water quality.[25]

I.7.2. Provision of Productive Soil

71. Productive soil is a matter of concern in the sustainability of agricultural and timber production. Soil productivity is related to a variety of factors, including organic matter content, compaction, salinization, acidity and availability of micro- and macro-nutrients. These are all parameters that are amenable to direct measurement, although they are not currently widely measured in Canada. If they were, it is possible to imagine that an index of soil productivity could be constructed for the country to serve as the basis for an indicator. In the absence of such measures, a proxy could be developed based on the need to apply chemical adjuncts to soil to replace lost natural productivity.

I.7.3. Provision of Biodiversity

72. Biodiversity is a matter of concern for sustainable development mainly because of the possibility that it offers for sources of useful new material. Because we are unaware of the potential represented by biodiversity, prudence would suggest that this natural capital be protected to the greatest extent possible for future use. A variety of approaches to measuring biodiversity are possible, including habitat measures, keystone species measures and endangered species measures. Further research is required to determine which of these approaches offers the greatest potential for a sustainable development indicator.

I.7.4. Provision of a Predictable and Stable Climate

73. Climatic predictability and stability are essential to the sustainability of economic production because of the adaptation of our current economic structure to the known range of climatic

---

[25] It is important to emphasize the need to maintain spatially disaggregated information in support of such an indicator. Even if a national population-weighted indicator of air or water quality showed a positive trend, there may be areas in which air or water quality was poor enough to be of concern. The information behind the indicators should allow this to be investigated.

extremes. If this range changes dramatically because of disruptions of global climate systems, the consequences for economic production and for the provision of other ecosystem outcomes (in particular, the supply of renewable resources) may be substantial. Again, further research is required to determine the most appropriate means of assessing climatic stability. The notion of creating an index based on climate normals, in which climatic parameters such as precipitation are averaged out of multi-decade moving intervals, presents a possible approach.

I.7.5. Provision of Protection from Solar Radiation

74. Above a certain level, the sun's ultraviolet radiation is extremely damaging to all forms of life. The ability of the ozone layer to protect us from this radiation is the outcome we wish to measure. An alternative approach would be to base an indicator on the incidence of solar radiation at the earth's surface at various points across the country during a given period. The feasibility of developing either of these indicators is a subject for further research.

I.7.6. Provision of Reliable Flows of Renewable Natural Resources

75. The outcome of this service is straightforwardly measured in terms of the size and quality of Canada's stocks of key renewable resources: timber and other flora, fish and terrestrial fauna. Since these are already proposed for measurement in the indicator of physical quantities of natural resources (5) above, there is no need to propose an additional indicator here.

I.8. Indicators of the Demand for Ecosystem Services

76. As mentioned at the outset of this section, a "third order" type of indicator can be developed by focusing on the demand for capital. This type is particularly appropriate for ecosystems. Although in principle it should be sufficient to develop indicators of the "second order" type for ecosystems, in practice it is probably not possible to develop indicators for all of the outcomes of ecosystem services. Some outcomes may not be known and others may not be amenable to measurement. For this reason, it is suggested that indicators of the demand for ecosystem services also be developed. These indicators should be of two sorts: indicators of the demand for renewable resources and indicators of waste emissions into the environment.

I.8.1. Demand for Renewable Resources

77. Indicators of the demand for renewable resources could be straightforwardly calculated. Indeed, in developing the indicator of physical quantities of natural resource stocks (5), it will be necessary to measure the extraction of timber and fish resources on an annual basis as part of the calculation of the change in stock level from one year to the next. In addition to timber and fish, it is suggested that a demand indicator be developed for water (for which it may not make sense to develop an accompanying stock indicator).

I.8.2. Emissions of Wastes

78. Waste emissions represent demands for ecosystem services that provide clean air and water (and soil for that matter). Excessive introduction of wastes into the environment can lead to reductions in the functioning of these services such that the quality of air, water and soil diminishes. For this reason, indicators of waste emissions are an appropriate component of a core set of sustainable development indicators.

79. In principle, it is not difficult to develop indicators of emissions for individual wastes (e.g.,

tonnes of carbon dioxide, litres of sulphuric acid). However, such an approach leads inevitably to dozens if not hundreds of separate indicators. Clearly, this is not appropriate in a core set of indicators. To avoid this, one of two approaches is possible. First, research could be applied to establishing means of combining various waste emissions into an aggregate indicator. This is already possible for selected categories of wastes (e.g., greenhouse gases), but a great deal more research would be required to determine if it is possible for a wider range of wastes. Alternatively, it may be possible to select a few "keystone" waste indicators that will serve as proxies for total waste loadings on the environment. These indicators could be supported by detailed data on a range of other waste emissions so that researchers wishing to know more about specific wastes would be able to seek out this information. Neither of these approaches to dealing with the difficulty presented by waste emissions is entirely satisfactory. Other solutions may well be necessary.