Growth, technological progress and sustainable development: preliminary evidence of Australia's sustainable development performance

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Abstract: In economic parlance, sustainable development is a case of non-declining economic welfare where economic welfare is the difference between the benefits and costs of economic activity. For various reasons, a measure of Gross Domestic Product (GDP) inadequately serves as an indicator of economic welfare and, therefore, of sustainable development. With the use of a linear throughput representation of the economic process, a range of alternative economic indicators is put forward to assess a nation's sustainable development performance. Calculation of these indicators for Australia for the period 1966-1967 to 1994-1995 suggests that Australia is failing to make the transition towards sustainable development – a consequence of Australia's inefficiency, its addiction to growth and its failure to embrace the notions of sufficiency, equity and natural capital maintenance.

Keywords: Sustainable development; performance indicators; Gross Domestic Product (GDP); Australia.

Reference to this paper should be made as follows: Lawn, P.A. (2003) 'Growth, technological progress and sustainable development: preliminary evidence of Australia's sustainable development performance', *Int. J. Environment and Sustainable Development*, Vol. 2, No. 2, pp.139-161.

Biographical notes: Philip Lawn is currently a lecturer in environmental and ecological economics at the Flinders University of South Australia. Since completing his PhD at Griffith University in Brisbane in 1997, Philip has published a number of papers on ecological economics issues as well as a book entitled *Toward Sustainable Development*. He is currently working on environmental macroeconomic models and a comprehensive set of sustainable development indicators to assess Australia's sustainable development performance.

1 Introduction

In a recent article, Mulder and van den Bergh [1] point out the importance of sustainable development as both a policy goal and as a central concept in the study of the interaction between the economy and the biophysical environment. Furthermore, when considering the link between sustainable development and growth, Mulder and van den Bergh argue that the types of policies, institutions and mechanisms required to achieve sustainable development can only be recognised if standard economics is complemented by a new approach that focuses on the coevolutionary nature of economic and environmental change. Fortunately, such an approach exists in the form of a new branch of economics called ecological economics [2].

It is the aim of this paper to employ an ecological economics approach to assess Australia's sustainable development performance. To achieve its aim, this paper is organised as follows. Firstly, an economic interpretation of sustainable development is put forward. Secondly, it will be argued that GDP is an inadequate sustainable development indicator. Thirdly, a linear throughput model is introduced:

- to demonstrate the link between sustainable development, growth and technological progress
- to outline five behavioural modes requiring satisfaction to achieve sustainable development
- to serve as the basis for more appropriate sustainable development indicators.

Finally, empirical evidence is used to indicate whether Australia is satisfying the five behavioural modes and, thus, whether the growth of the Australian economy is moving Australia towards the sustainable development goal.

Before moving on, two important points need to be made. In the first instance, it is hoped that the sustainable development indicators developed in this paper could be used to assess the sustainable development performance of any nation. Having said this, different cultural perceptions of human betterment may demand different interpretations of the various indicators. In the second instance, the paper is more about how to begin the process of establishing more appropriate sustainable development indicators. I readily admit that the evidence regarding Australia's sustainable development performance is somewhat fragile if only because the methods employed to estimate some of the sustainable development indicators were rather crude. In addition, some of the data sources cannot be regarded as totally reliable. Hence, before one can confidently remark on a nation's sustainable development performance, it is necessary to generate better data sources and to strive for more robust valuation techniques [3].

2 An economic interpretation of sustainable development

Generally speaking, sustainable development can be defined as a pattern of development that improves the total quality of life of a nation's citizens, both now and into the future, without destroying the ecological processes upon which life in all its diversity depends [4]. At the very least, achieving sustainable development demands that the welfare of a nation's citizens be sustained over time. Hence, from an economic perspective, sustainable development can be regarded as a pattern of economic activity that results in *non-declining economic welfare*. Since economic welfare is the difference between the benefits and costs of economic activity, an assessment of a nation's sustainable development performance requires indicators that identify, measure and compare the full range of benefits and costs associated with the economic process – including social and environmental benefits and costs. Clearly, no single economic or non-economic indicator will ever convey the information necessary to make precise judgments about a nation's sustainable development performance. However, well-constructed indexes that take account of the coevolutionary feedbacks of past economic activities should, when taken together, provide a much clearer picture of how a nation is performing.

3 Why GDP is an inadequate indicator of sustainable development

Despite the growing degradation of ecological systems, the continuing rise in GDP is invariably regarded as confirmation of the successful transition towards sustainable development. After all, if a nation is failing, wouldn't its GDP decline? Whether this is so depends very much on how well GDP reflects the non-declining or sustainable economic welfare of a nation's citizens. GDP is a monetary estimate of the goods and services annually produced by domestically located factors of production. Included in a measure of GDP are many costs – for example, the cost of vehicle repairs, the cost of environmental rehabilitation, the cost of crime and the cost of commuting. Paradoxically, GDP excludes such benefits as the value of unpaid household and volunteer work, the value of increased leisure time (or the cost of reduced leisure time) and the services provided by existing public assets (e.g., roads, highways, museums and art galleries). In addition, GDP fails to take account of the welfare effect of a change in a nation's foreign debt, of fluctuating unemployment levels and of an improvement/deterioration in the distribution of income. Thus, in contrast to the need to keep the benefits and costs of economic activity separate, GDP counts many costs as benefits while it ignores some benefits and costs altogether. Clearly, GDP is a very poor indicator of sustainable economic welfare.

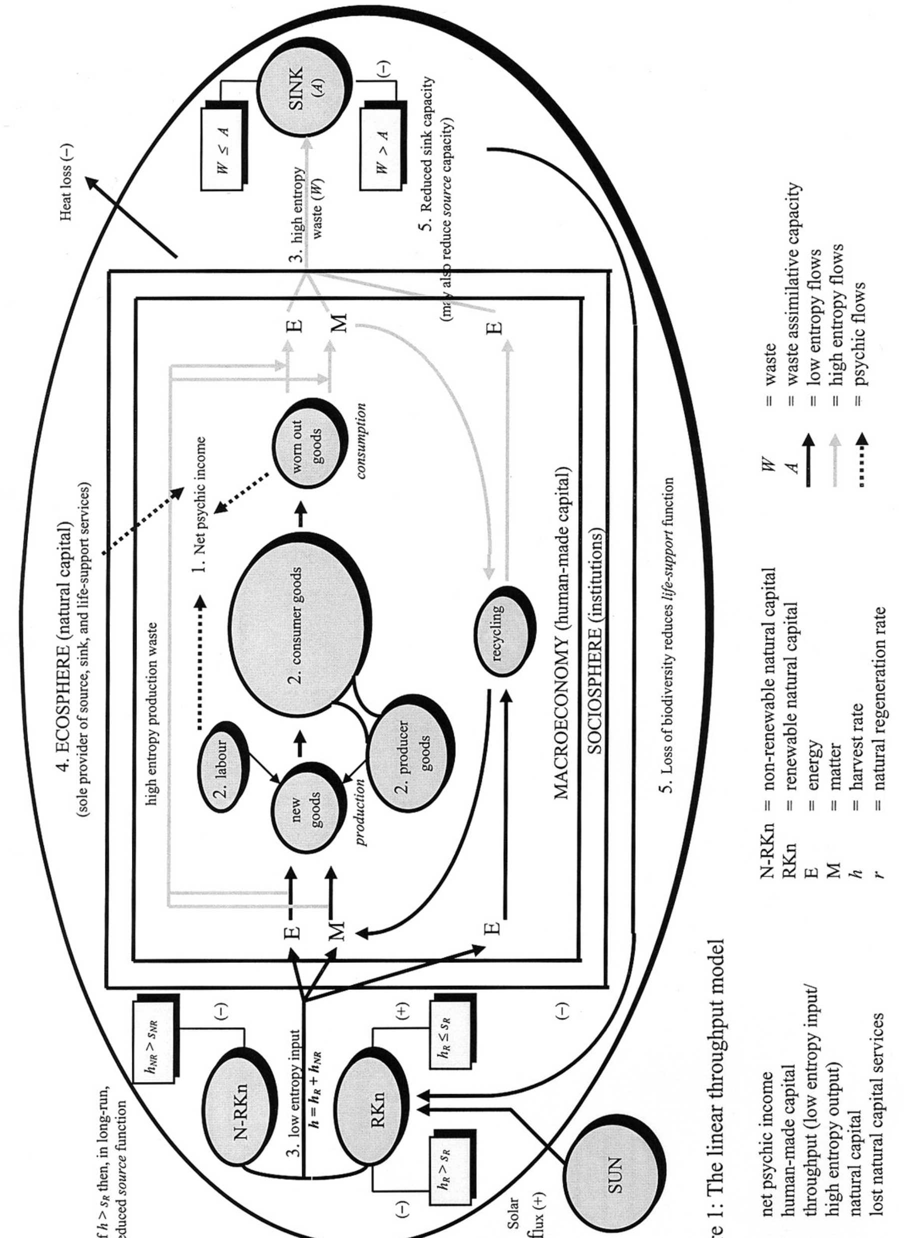
4 A linear throughput representation of the economic process

Given Mulden and van den Bergh's call for an environmental economics that focuses on the coevolutionary nature of economic and environmental change, the quest for more appropriate sustainable development indicators must start within the context of a concrete representation of the economic process. Consider Figure 1, which is a linear throughput model of an economic system.

Unlike the conventional circular flow model found in economics textbooks, the linear throughput model depicts the economy as a subsystem of the sociosphere that, in turn, is depicted as a subsystem of the natural environment. By tracing economic activity from its original source to its ultimate conclusion, the linear throughput model highlights two very important aspects. Firstly, by identifying the ongoing exchange and feedback of matter, energy and information, the linear throughput model highlights the coevolutionary relationship between the economy, the sociosphere and the natural environment. Indeed, by including the sociosphere as the interface between the economy and the natural environment, the linear throughput model emphasises the important role that institutions play in both instigating change and promoting stable human behaviour in a world characterised by indeterminacy, novelty and surprise [5]. Secondly, the linear throughput model reveals five macro magnitudes applicable to the economic process. These magnitudes are of great value insofar as they can subsequently form the basis for:

- better understanding the link between sustainable development and the growth of economic systems
- revealing how structural and technological change can assist in achieving sustainable development
- establishing suitable sustainable development indicators.

Figure 1 The linear throughput model



The first of the five magnitudes requiring elaboration is *natural capital*. Natural capital constitutes the original source of all economic activity insofar as it is the only source of low entropy resources; it is the ultimate assimilator of high entropy wastes; and it is the sole provider of a range of life-support services that are necessary to maintain the habitability of planet Earth [6]. The second macro magnitude is the *throughput* of matter-energy — that is, the input into the economy of low entropy resources and the subsequent output of high entropy wastes back into the natural environment. The throughput flow is the physical intermediary connecting natural and human-made capital. *Human-made capital* is the third macro magnitude and is needed for human welfare to be greater than what would otherwise be experienced if the economic process did not take place. Since, for the purposes of this paper, human-made capital will be defined as all benefit-yielding goods capable of human ownership, human-made capital will include consumer goods as well as producer goods [7]. For simplicity, it will be assumed that the stock of human-made capital also includes human labour. The fourth macro magnitude is *net psychic income* — the difference between the desirable 'psychic income' and the undesirable 'psychic outgo' generated by economic activity. Psychic income is normally referred to by economists as 'utility satisfaction' and is the benefit that flows from human-made capital as elements are either consumed (e.g., food and petrol) or worn out through use (e.g., machinery, houses, clothes and consumer durables). Psychic outgo, on the other hand, is the disbenefit that arises from having to engage in undesirable aspects of the economic process (e.g., unpleasant forms of work, commuting and noise pollution). Net psychic income can be regarded as the 'uncancelled benefit' of economic activity because, if one traces the economic process from its original source to its final conclusion, every transaction involves the cancelling out of a receipt and expenditure of the same magnitude (i.e., a seller receives what the buyer pays). Only once a physical good is in the possession of the final consumer is there no further exchange and, thus, no further cancelling out of transactions. Apart from the good itself, what remains at the end of the process is the uncancelled exchange value of the psychic income the ultimate consumer expects to gain from the good, plus any psychic disbenefits and other costs associated with the good's production. Note, therefore, that if the costs are subtracted from the good's final selling price, the difference constitutes the 'use value' added during the production process as the low entropy resources provided by natural capital are transformed into human-made capital. Presumably the difference is positive, otherwise the economic process is a pointless exercise.

The fifth macro magnitude is the cost of *lost natural capital services* and arises because, in obtaining the throughput to produce and maintain human-made capital, some of the services provided by natural capital are inevitably lost [8]. In a similar way to net psychic income, lost natural capital services constitute the 'uncancelled cost' of economic activity [9]. That is, imagine tracing the economic process from its ultimate conclusion back to the natural capital. All transactions would cancel out, however, what remains is the uncancelled exchange value of any sacrificed natural capital services [10].

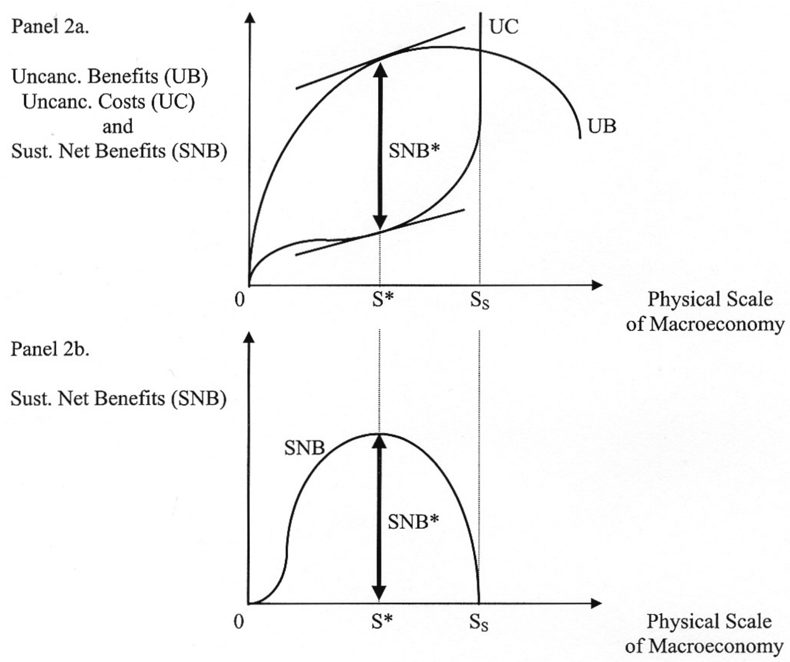
In sum, the linear throughput model illustrates the following. Natural capital provides the throughput of resources that is needed to produce and maintain the stock of human-made capital (i.e., natural capital → throughput → human-made capital). Human-made capital is needed to enjoy a level of net psychic income greater than what would otherwise be experienced if the economic process did not take place (i.e., human-made capital → net psychic income). Finally, in manipulating and exploiting natural capital for the throughput of resources, the source, sink and life-support services that natural capital provides are, to some degree, unavoidably sacrificed (i.e., lost natural capital services → natural capital → throughput → human-made capital → net psychic income).

The linear throughput model also shows that natural and human-made capital are complementary forms of capital. Although technological progress embodied in human-made capital can reduce the resource flow required from natural capital to produce physical goods, for two related reasons, this does not amount to substitution [11]. Firstly, technological progress only reduces the high entropy waste generated in the transformation of natural to human-made capital. Secondly, because of the first and second laws of thermodynamics, there is a limit to how much production waste can be reduced by technological progress – there can be no 100% production efficiency; there can never be 100% recycling of matter; and there is no way to recycle energy at all [12]. Thus, the production of a given quantity of human-made capital will always require a minimum resource flow and, therefore, a minimum amount of resource-providing natural capital [13].

5 Growth and sustainable development

Two of the five magnitudes revealed by the linear throughput model – namely, net psychic income (uncancelled benefits) and lost natural capital services (uncancelled costs) – can be diagrammatically presented to demonstrate the sustainable development impact of a growing economy. Consider Figure 2 where, for the moment, it is assumed that there is no technological progress.

Figure 2 The changing sustainable net benefits from a growing macroeconomy



The uncancelled benefit (UB) curve in Panel 2a represents the net psychic income generated by a growing national economy. The characteristic shape of the UB curve is attributable to the law of diminishing marginal benefits. The cost of a growing economy is represented in Panel 2a by an uncancelled cost (UC) curve. It represents the natural capital services lost in the process of transforming natural capital and the low entropy it provides into human-made capital. The shape of the UC curve is attributable to the law of increasing marginal costs. This law applies to an economic system because its expansion relative to a finite natural environment increases the cost of the undesirable ecological feedbacks associated with each additional disruption of natural capital. The UC curve is vertical at a physical economic scale of S_S. This is because S_S denotes the *maximum sustainable* scale – what is, for given levels of human know-how, the largest economic scale a nation can sustain at the maximum sustainable rate of resource throughput.

For any given economic scale, sustainable economic welfare is measured by the vertical difference between the UB and UC curves. This difference is represented by the sustainable net benefits (SNB) curve in Panel 2b. S_* is where the SNB curve is at its highest point and represents the physical scale of the economy that maximises a nation's sustainable economic welfare (SNB_*). Note that when technological progress is assumed to be fixed, growth is only desirable in the early stages of a nation's developmental process. Continued physical expansion of the economic subsystem, which is equivalent to moving along the UB and UC curves, is antithetic to the sustainable development goal because it eventually leads to a decline in sustainable economic welfare.

6 Technology, structural change and sustainable development

It is impossible to ignore the critical role that advances in technology play in the development process. For example, technological progress can increase the net psychic income gained and decrease the natural capital services sacrificed when maintaining a given economic scale. This is because technological progress and the structural change it promotes can beneficially shift the UB curve upwards and the UC curve downwards and to the right. Furthermore, technological progress can also increase the maximum sustainable scale of a macroeconomic system. In other words, it can permit a larger macroeconomic system to be sustained by the ecosphere upon which it depends. To explain how the UB and UC curves can be positively shifted, two of the five key magnitudes of the linear throughput model can be arranged to represent a measure of ecological economic efficiency (EEE). The ratio is as follows [14,p.84]:

$$\text{EEE} = \frac{\textit{net psychic income}}{\textit{lost natural capital services}} \tag{1}$$

For a given physical scale of the economy, an increase in the EEE ratio indicates an improvement in the efficiency with which natural capital is transformed into human-made capital. A multitude of factors can be shown to contribute to an increase in the EEE ratio. To demonstrate how, the EEE ratio can be unfolded to reveal four component ratios. The EEE ratio thus becomes the following identity:

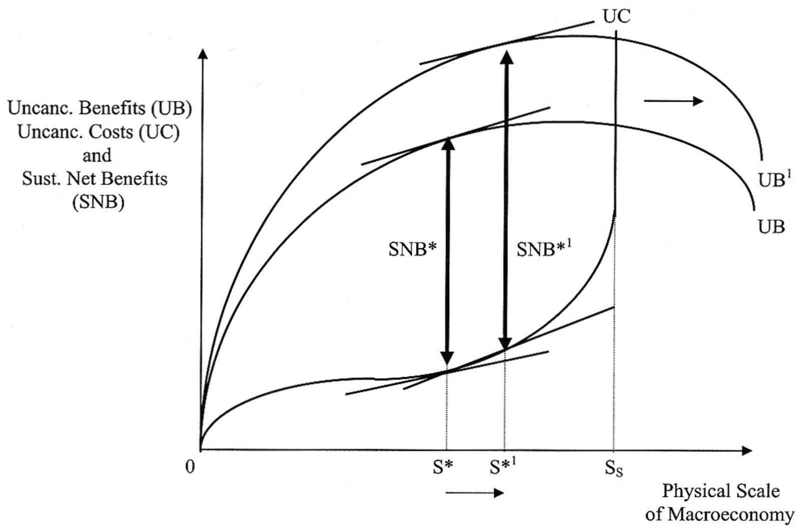
$$\text{EEE}=\frac{\textit{net psychic income}}{\textit{lost natural capital services}}=\underbrace{\frac{\textit{net psychic income}}{\textit{human-made capital}}}_{\text{Ratio 1}}\ x\ \underbrace{\frac{\textit{human-made capital}}{\textit{throughput}}}_{\text{Ratio 2}}\ x\ \underbrace{\frac{\textit{throughput}}{\textit{natural capital}}}_{\text{Ratio 3}}\ x\ \underbrace{\frac{\textit{natural capital}}{\textit{lost natural capital services}}}_{\text{Ratio 4}} \qquad (2)$$

Starting from Ratio 1 and progressing through to Ratio 4, each component ratio cancels the ensuing ratio out. This leaves the basic EEE ratio on the left-hand side. The order in which the four component ratios are presented is in keeping with the conclusions drawn from the linear throughput representation of the economic process – i.e., the net psychic income from economic activity is enjoyed as a consequence of the existence of human-made capital (Ratio 1); human-made capital exists as a consequence of the throughput of resources (Ratio 2); the throughput of resources is only possible because of the existence of natural capital (Ratio 3); and, in exploiting natural capital, the three instrumental services provided by natural capital are, to some degree, sacrificed (Ratio 4). Each component ratio represents a different form of efficiency and will now be individually explained and discussed.

Ratio 1 is a measure of the *service efficiency* of human-made capital. It increases whenever a given physical magnitude, though not the same population, of human-made capital yields a higher level of net psychic income. An increase in Ratio 1 causes the UB curve to shift upwards and can be achieved by improving the technical design of newly produced commodities. It can also be achieved by improving the manner in which human beings organise themselves in the course of producing and maintaining the stock of human-made capital, thereby reducing such things as the disutility of labour and the cost of commuting and unemployment.

A beneficial upward shift in the UB curve can also be achieved by distributing the stock of human-made capital more equitably. Often overlooked, the redistribution of income from the low marginal service or psychic income uses of the rich to the higher marginal service uses of the poor can lead to an overall increase in the net psychic income enjoyed by society as a whole [15]. There is, however, a limit on the capacity for redistribution to increase Ratio 1 because an excessive approach to redistribution adversely dilutes the incentive structure built into a market-based system. Figure 3 illustrates what happens to sustainable economic welfare when the UB curve shifts upwards. Because an increase in Ratio 1 augments the net psychic income yielded by a given magnitude of human-made capital, the UB curve shifts up to UB^1. The UC curve does not move since the uncancelled cost of producing and maintaining a given stock of human-made capital remains unchanged. Moreover, the maximum sustainable scale remains at S_S.

Figure 3 A change in sustainable net benefits brought about by an increase in the service efficiency of human-made capital (Ratio 1)



Prior to the increase in the service efficiency of human-made capital, sustainable economic welfare is greatest at an economic scale of S* (where sustainable net benefits equal SNB*). Following an increase in the service efficiency of human-made capital, sustainable economic welfare is greatest at a scale of S^{*1} where sustainable net benefits equal SNB^1. It is now desirable to expand the physical scale of the economy to S^{*1}.

Changes in Ratios 2, 3 and 4 cause the UC curve to shift. Ratio 2 is a measure of the *maintenance efficiency* of human-made capital. It increases whenever a given physical magnitude of human-made capital can be maintained by a lessened rate of resource throughput. This can be achieved by developing new technologies that reduce the requirement for resource input either through:

- the more efficient use of resources in production
- increased rates of product recycling
- greater product durability
- improved operational efficiency.

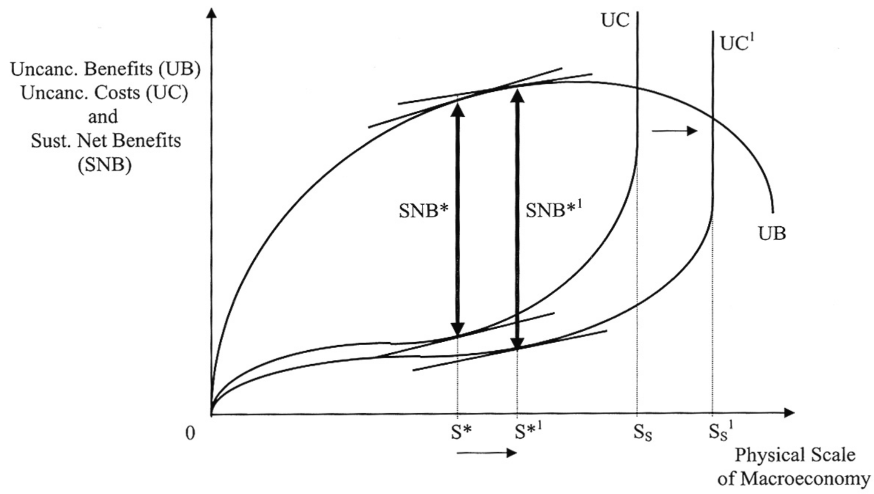
An increase in Ratio 2 causes the UC to shift downwards and to the right for the following reasons. Firstly, it enables any given economic scale to be sustained by a reduced rate of resource throughput. Secondly, a lower rate of throughput means not having to exploit as much natural capital which means a reduction in the natural capital services lost.

Ratio 3 is a measure of the *growth efficiency* or productivity of natural capital. This form of efficiency is increased whenever a given amount of natural capital is able to yield sustainably a greater quantity of low entropy resources and assimilate more of the high entropy waste that economic activity generates. Better management of natural resource systems and the preservation of critical ecosystems can lead to a more productive stock of natural capital. How does an increase in Ratio 3 lead to a downward and rightward shift of the UC curve? An increase in the productivity of natural capital reduces the quantity of natural capital that must be exploited to sustain the economy at a given physical scale. This, in turn, means an economic system of a given physical scale can be sustained at the expense of fewer natural capital services.

Ratio 4 is a measure of the *exploitative efficiency* of natural capital. If Ratio 4 increases, fewer natural capital services are lost in exploiting a given quantity of natural capital. This, again, allows an economic system of a given physical scale to be sustained at the expense of fewer natural capital services and, thus, to a downward and rightward shift of the UC curve. Increases in Ratio 4 can be obtained through the development and execution of more ecologically sensitive extractive techniques such as the use of underground rather than open-cut or strip mining practices.

Figure 4 illustrates what happens to sustainable net benefits when there is a shift of the UC curve. Because an increase in Ratios 2, 3 and 4 reduces the uncancelled cost of producing and maintaining a given economic scale, the UC curve shifts down and out to UC^1. However, the UB curve remains stationary since an increase in these three efficiency ratios does not augment the net psychic income yielded by a given stock of human-made capital. Unlike a shift in the UB curve, a shift in the UC curve results in an increase in the maximum sustainable scale (S_S to S_S^1). The logic behind this is quite simple. If there are now fewer natural capital services sacrificed in maintaining what was previously the maximum sustainable scale, a larger economic subsystem can now be ecologically sustained from the same loss of natural capital services.

Figure 4 A change in sustainable net benefits brought about by increases in the maintenance efficiency of human-made capital (Ratio 2), and the growth and exploitative efficiencies of natural capital (Ratios 3 and 4)



Prior to further increases in either the maintenance efficiency of human-made capital and/or the growth and exploitative efficiency of natural capital, sustainable economic welfare is greatest when operating at an economic scale of S* (where sustainable net benefits equal SNB*). Upon an increase in Ratios 2, 3 and/or 4, sustainable economic welfare is greatest at a scale of S^{*1} where they now equal SNB^1. It is now desirable to expand the physical scale of the economy to S^{*1}.

7 Real and potential limits to technological progress

Exactly how much and for how long human beings can rely on technological progress to shift the UB and UC curves is a considerable topic of debate. Due to thermodynamic and biophysical constraints, ecological economists believe the ability of technological progress to reduce the uncancelled cost of economic activity by increasing Ratios 2, 3 and 4 is inevitably limited [12,14,16]. Moreover, they believe these limits are fast approaching. Conclusions regarding limits to increases in the service efficiency of human-made capital (Ratio 1) are harder to draw because net psychic income is a psychic rather than physical magnitude. Whilst it is difficult to believe that a given quantity of human-made capital could yield increasing levels of net psychic income, such limits are probably some distance away. Indeed, so much so, they may be of little policy relevance.

Nevertheless, in view of the thermodynamic and biophysical limits to positively shifting the UC curve, a few things are irrefutably clear. Firstly, there is an inevitable limit to the maximum sustainable scale of the economic subsystem. Secondly, whilst the physical expansion of the economy is beneficial in the early stages of a nation's 'developmental' process and should therefore be the short and medium-term goal of impoverished nations, the growth objective must at some stage give way to a policy aimed at:

- the qualitative improvement of human-made capital
- a reduction in the psychic disbenefits associated with maintaining the stock intact.

Finally, provided the throughput of resources required to maintain an improving stock of human-made capital is kept within the regenerative and assimilative capacities of natural capital, a nation is able to achieve sustainable development without the assumed need for continued growth.

8 Assessing Australia's sustainable development performance

Given the complementarity between natural and human-made capital and the biophysical limits to growth, achieving sustainable development requires a nation to orient its endeavours in line with the following five behavioural modes:

1 Accumulate human-made capital until the stock reaches a *sufficient* physical magnitude. Sufficient is best defined in terms of the quantity at which any further growth leads to a decline in sustainable economic welfare. The best indicator of a sufficient stock of human-made capital is a sustainable net benefit (SNB) index.

2 *Maximise* the psychic enjoyment of life (net psychic income) subject to the sufficient accumulation and equitable distribution of human-made capital (maximise Ratio 1). This requires the qualitative improvement in the stock of human-made capital over time, not its continual physical expansion.

3 *Minimise* the throughput of resources required to maintain the sufficient magnitude of human-made capital intact (maximise Ratio 2).

4 Maintain natural capital intact and, where feasible, *maximise* its productivity — that is, maximise its ability to generate a flow of renewable low entropy resources and its ability to assimilate high entropy wastes (maximise Ratio 3).

5 *Minimise* the natural capital services lost in the process of exploiting natural capital for the throughput of matter-energy needed to fuel the economic process (maximise Ratio 4).

Since there is a close association between the above listed human behavioural modes and both sustainable economic welfare and the previously described efficiency ratios, how is Australia performing or 'behaving'? To find out, it is necessary to compile uncancelled benefit, uncancelled cost, human-made capital and natural capital accounts. This I have done for Australia for the period 1966-1967 to 1994-1995. Because the compilation of a throughput account was a more difficult proposition, the annual consumption of energy was used as a proxy measure of resource throughput. Due to a lack of space and the extensive and unique nature of the study, a full explanation of the individual accounts, the items they comprise, data sources and the methods of calculation can be found in Lawn [17].

As per Figure 2, the uncancelled benefit and cost accounts can be used to calculate a measure of sustainable economic welfare. Figure 5 draws a comparison between per capital real GDP and a per capita sustainable net benefit (SNB) index over the study period. It shows that whilst per capita real GDP has increased in almost every year, the SNB index has not. The SNB index rose from 1966-67 to 1973-74 but has been largely in decline ever since. This suggests that sustainable economic welfare in Australia has been falling for most of the last 20-odd years. Similar indexes, such as the Index of Sustainable Economic Welfare (ISEW) and Genuine Progress Indicator (GPI), which have been calculated for the USA [18], the UK [19], Germany [20], Austria [21], Sweden [22], The Netherlands [23] and Chile [24] indicate a similar pattern (see Figure 6).

Figure 5 Per capita sustainable net benefits and per capita real GDP for Australia, 1966-1967 to 1994-1995

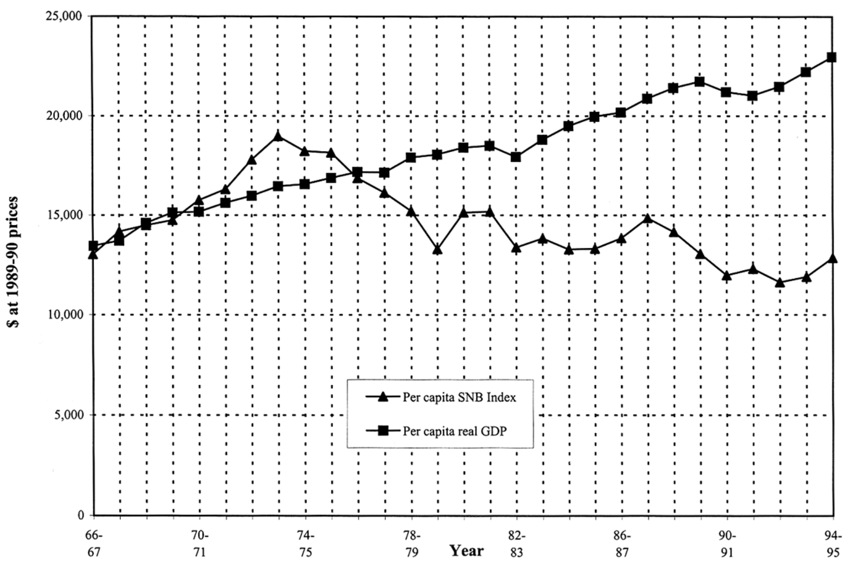
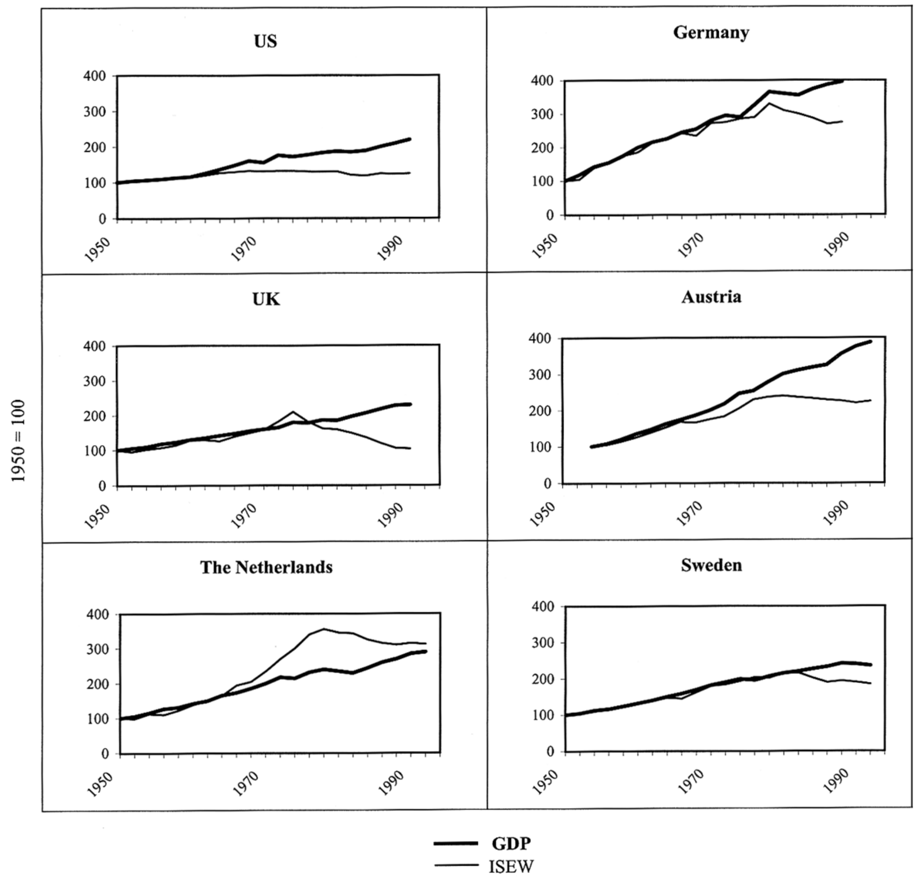


Table 1 and Figure 7 reveal the service efficiency of Australia's human-made capital (Ratio 1). They both show that Australia's service efficiency rose from 1966-1967 to 1972-1973 but has been falling in most years since. Why would this be so when, presumably, the stock of human-made capital is qualitatively improving over time? Although not provided in this paper (see [2, Table 14.1]), the uncancelled benefit account shows that whilst psychic income has continued to rise, it is has been rising at a slower rate than psychic outgo (e.g., the cost of such things as commuting, noise pollution, unemployment, etc.). In other words, the stock of human-made capital is generating more psychic benefits but is coming at the expense of much higher psychic disbenefits. Consequently, Figure 7 indicates that Australia is violating behavioural mode 2. Note also from Table 1 that the stock of human-made capital has increased over the study period. The Australian macroeconomy has continued to expand, which, in view of the declining SNB index, means the stock of human-made capital has probably exceeded the sufficient level [25]. It is doubtful, therefore, whether Australia has satisfied behavioural mode 1.

Figure 6 Comparison of GDP and ISEW for the USA, Germany, UK, Austria, The Netherlands, and Sweden

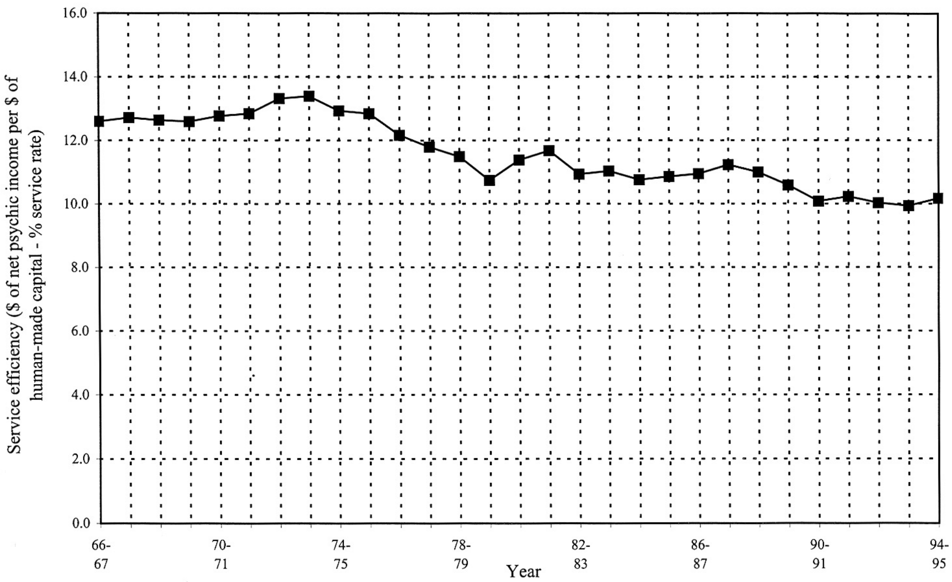


Source: Jackson and Stymne [22]

Table 1 Service efficiency ratio for Australia, 1966-1967 to 1994-1995

Year	*Uncancelled benefits ($m at 1989-90 prices)*	*Human-made capital stock ($m at 1989-90 prices)*	*Service efficiency (Ratio 1) (a/b)*
	a	*b*	*c*
1966-67	262,606	2,084,135	0.126
1967-68	282,956	2,225,354	0.127
1968-69	294,981	2,333,700	0.126
1969-70	306,639	2,434,665	0.126
1970-71	332,281	2,601,301	0.128
1971-72	347,843	2,707,916	0.128
1972-73	375,789	2,821,276	0.133
1973-74	401,192	2,995,896	0.134
1974-75	398,862	3,083,698	0.129
1975-76	405,100	3,153,572	0.128
1976-77	394,768	3,244,952	0.122
1977-78	391,465	3,319,701	0.118
1978-79	386,852	3,366,208	0.115
1979-80	367,096	3,416,009	0.107
1980-81	402,592	3,535,944	0.114
1981-82	412,625	3,532,734	0.117
1982-83	392,483	3,588,416	0.109
1983-84	406,404	3,682,232	0.110
1984-85	406,801	3,781,370	0.108
1985-86	415,492	3,825,766	0.109
1986-87	431,925	3,946,069	0.109
1987-88	457,233	4,071,717	0.112
1988-89	454,252	4,130,657	0.110
1989-90	447,247	4,224,225	0.106
1990-91	435,961	4,325,592	0.101
1991-92	448,485	4,384,474	0.102
1992-93	445,182	4,439,785	0.100
1993-94	455,611	4,585,704	0.099
1994-95	479,328	4,712,174	0.102

Figure 7 Service efficiency ratio (Ratio 1) for Australia, 1966-67 to 1994-95



The maintenance efficiency ratio (Ratio 2) is revealed in Table 2 and Figure 8. They both show that the energy consumed to maintain a given amount of human-made capital was at its lowest level in 1970-1971 (when Ratio 2 was at its highest). Since then, Ratio 2 has fallen, suggesting that behavioural mode 3 has also been violated. This is particularly interesting because many studies in the past on the energy efficiency of economic activity have indicated a steady improvement. The misleading nature of these studies is due largely to the fact that they have been based on GDP/energy ratios instead of human-made capital/energy ratios, as has been calculated here. The problem with GDP/energy ratios is that a measure of GDP includes the cost of energy use and so energy appears in both the numerator and the denominator of the efficiency ratio.

Table 2 Maintenance efficiency ratio for Australia, 1966-1967 to 1994-1995

Year	*Human-made capital stock ($m at 1989-90 prices)*	*Total energy consumption (throughput) (Petajoules)*	*Maintenance efficiency (Ratio 2) (a/b)*
	a	*b*	*c*
1966-67	2,084,135	1,805.8	1,154.1
1967-68	2,225,354	1,898.9	1,171.9
1968-69	2,333,700	2,025.9	1,151.9
1969-70	2,434,665	2,137.6	1,139.0
1970-71	2,601,301	2,210.3	1,176.9
1971-72	2,707,916	2,331.2	1,161.6
1972-73	2,821,276	2,447.8	1,152.6
1973-74	2,995,896	2,615.1	1,145.6
1974-75	3,083,698	2,694.5	1,144.4
1975-76	3,153,572	2,730.6	1,154.9
1976-77	3,244,952	2,905.6	1,116.8
1977-78	3,319,701	2,982.7	1,113.0
1978-79	3,366,208	3,050.9	1,103.3
1979-80	3,416,009	3,130.2	1,091.3
1980-81	3,535,944	3,146.1	1,123.9
1981-82	3,532,734	3,236.5	1,091.5
1982-83	3,588,416	3,122.9	1,149.1
1983-84	3,682,232	3,220.4	1,143.4
1984-85	3,781,370	3,369.6	1,122.2
1985-86	3,825,766	3,403.0	1,124.2
1986-87	3,946,069	3,514.8	1,122.7
1987-88	4,071,717	3,622.3	1,124.1
1988-89	4,130,657	3,832.1	1,077.9
1989-90	4,224,225	3,945.2	1,070.7
1990-91	4,325,592	3,946.6	1,096.0
1991-92	4,384,474	4,003.2	1,095.2
1992-93	4,439,785	4,079.2	1,088.4
1993-94	4,585,704	4,176.6	1,098.0
1994-95	4,712,174	n.a..	n.a.

Note: n.a. denotes not available

Figure 8 Maintenance efficiency ratio (Ratio 2) for Australia, 1966-1967 to 1994-1995

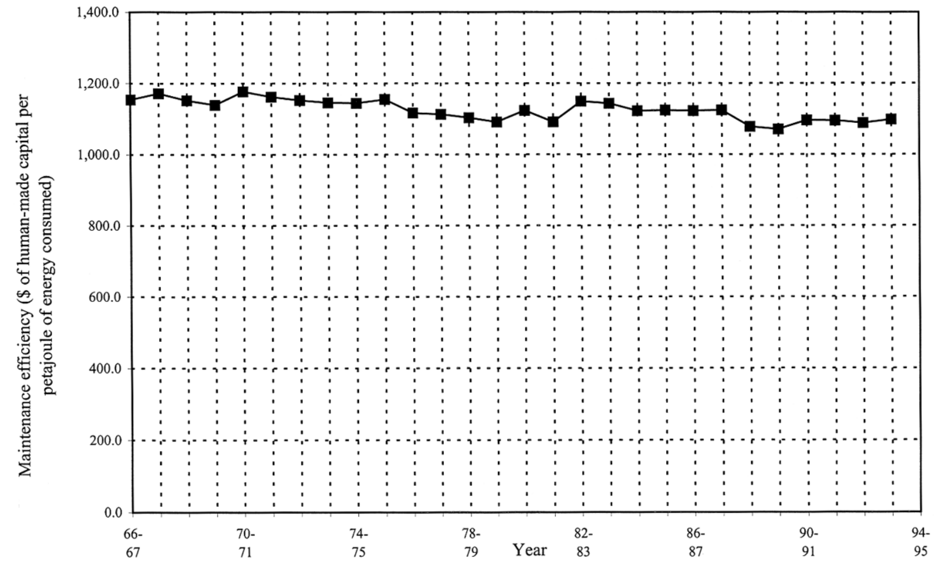


Figure 9 Natural capital growth efficiency ratio (Ratio 3) for Australia, 1966-1967 to 1994-1995

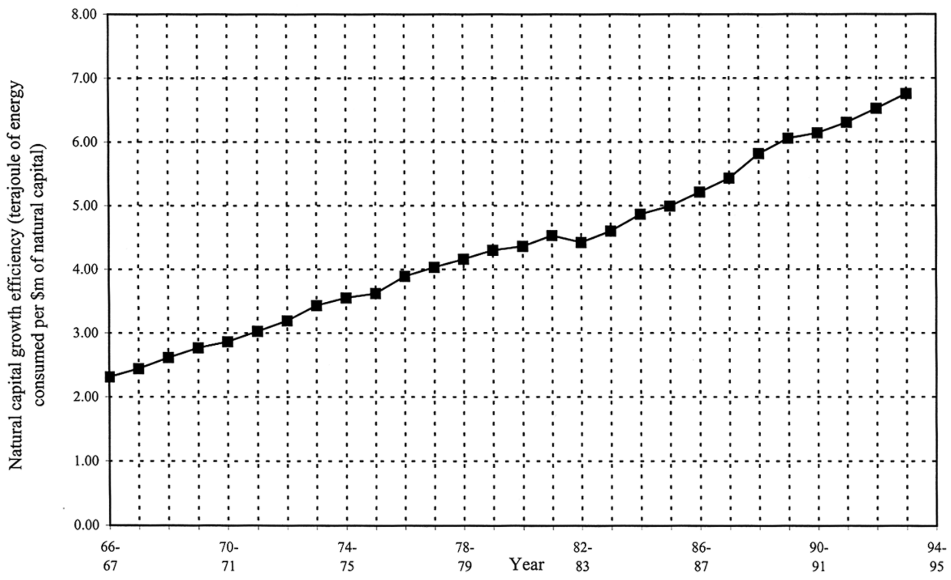


Table 3 and Figure 9 reveal the growth efficiency of Australia's natural capital (Ratio 3). This ratio increased over the study period suggesting that Australia's natural capital became progressively more productive (i.e., increasingly able to generate the flow of low entropy resources and assimilate high entropy waste). This too, is misleading, because the continued rise in Australia's energy consumption was only made possible by the increase in the depletion rate of non-renewable energy stocks. This also means that Australia has failed to invest enough of the proceeds from non-renewable resource depletion into the cultivation of additional renewable resources to keep the total stock of natural capital intact [26]. It is therefore unlikely that Australia could sustain its current rate of energy consumption into the future. This constitutes a very good reason for believing Australia has violated behavioural mode 4.

Table 3 Natural capital growth efficiency ratio for Australia, 1966-1967 to 1994-1995

Year	*Total energy consumption (throughput) (Terajoules)*	*Natural capital stock ($m at 1989-90 prices)*	*Natural capital growth efficiency (Ratio 3) (a/b)*
	a	b	c
1966-67	1,805,800	780,448	2.31
1967-68	1,898,900	777,952	2.44
1968-69	2,025,900	775,057	2.61
1969-70	2,137,600	772,290	2.77
1970-71	2,210,300	771,314	2.87
1971-72	2,331,200	769,665	3.03
1972-73	2,447,800	766,550	3.19
1973-74	2,615,100	762,221	3.43
1974-75	2,694,500	758,384	3.55
1975-76	2,730,600	754,000	3.62
1976-77	2,905,600	746,602	3.89
1977-78	2,982,700	739,869	4.03
1978-79	3,050,900	733,361	4.16
1979-80	3,130,200	727,961	4.30
1980-81	3,146,100	721,292	4.36
1981-82	3,236,500	714,341	4.53
1982-83	3,122,900	706,361	4.42
1983-84	3,220,400	700,039	4.60
1984-85	3,369,600	692,692	4.86
1985-86	3,403,000	681,766	4.99
1986-87	3,514,800	674,395	5.21
1987-88	3,622,300	666,835	5.43
1988-89	3,832,100	658,973	5.82
1989-90	3,945,200	651,192	6.06
1990-91	3,946,600	642,862	6.14
1991-92	4,003,200	634,924	6.31
1992-93	4,079,200	625,177	6.52
1993-94	4,176,600	618,259	6.76
1994-95	n.a.	608,912	n.a.

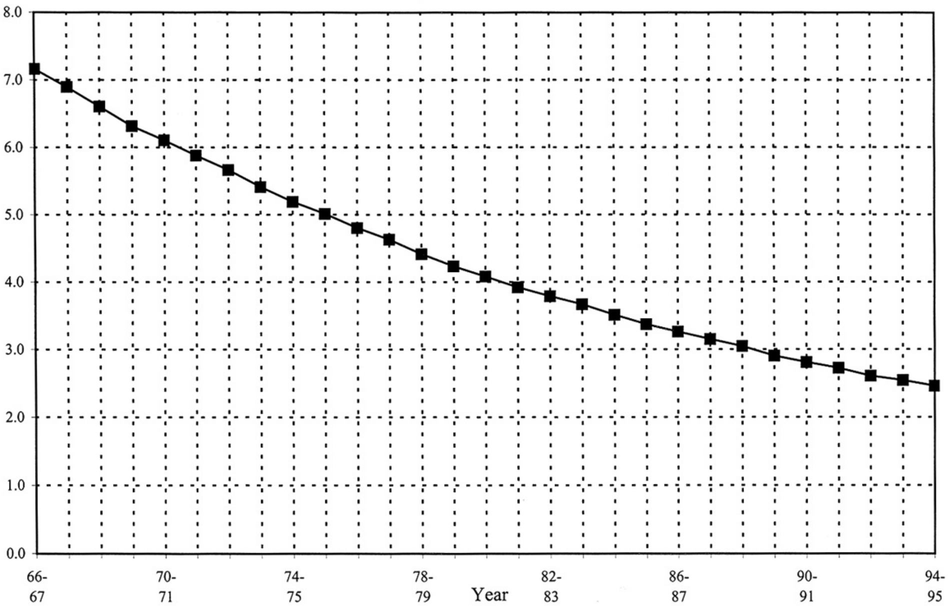
Note: n.a. denotes not available

A measure of the exploitative efficiency of Australia's natural capital (Ratio 4) is revealed in Table 4 and Figure 10. This ratio fell in every year over the study period indicating that the uncancelled cost of economic activity per unit of natural capital exploited continued to rise. The main reasons for this appear to be Australia's reliance on non-renewable resources, the growing problem of land degradation and the continuing large-scale clearance of native vegetation – a clear indication that Australia is failing adequately to manage its land resources and, moreover, failing to meet the condition associated with behavioural mode 5.

Table 4 Natural capital exploitative efficiency ratio for Australia, 1966-1967 to 1994-1995

Year	*Natural Capital Stock ($m at 1989-90 prices)*	*Uncancelled costs ($m at 1989-90 prices)*	*Natural capital exploitative efficiency (Ratio 4) (a/b)*
	a	b	c
1966-67	780,448	108,941	7.2
1967-68	777,952	112,830	6.9
1968-69	775,057	117,306	6.6
1969-70	772,290	122,265	6.3
1970-71	771,314	126,338	6.1
1971-72	769,665	130,902	5.9
1972-73	766,550	135,338	5.7
1973-74	762,221	140,820	5.4
1974-75	758,384	146,047	5.2
1975-76	754,000	150,430	5.0
1976-77	746,602	155,479	4.8
1977-78	739,869	159,814	4.6
1978-79	733,361	166,103	4.4
1979-80	727,961	171,962	4.2
1980-81	721,292	176,748	4.1
1981-82	714,341	182,239	3.9
1982-83	706,361	186,395	3.8
1983-84	700,039	190,907	3.7
1984-85	692,692	197,236	3.5
1985-86	681,766	202,215	3.4
1986-87	674,395	206,729	3.3
1987-88	666,835	211,570	3.2
1988-89	658,973	216,289	3.0
1989-90	651,192	224,187	2.9
1990-91	642,862	228,905	2.8
1991-92	634,924	233,111	2.7
1992-93	625,177	239,809	2.6
1993-94	618,259	243,097	2.5
1994-95	608,912	247,534	2.5

Figure 10 Natural capital exploitative efficiency (Ratio 4) for Australia, 1966-1967 to 1994-1995



In all, since Australia appears to be violating all five behavioural modes, it is performing very poorly in terms of making the transition towards sustainable development. Of course, a conclusion of this nature depends very much on the validity of the indicators put forward in this paper and the methods used to calculate the items that make up the various accounts. As it turns out, these alternative indicators are far from perfect [27]. For instance, to estimate the values of the respective indicators, heroic assumptions have been made and many crude valuation techniques have been adopted. They are also valued in monetary terms when many would be of greater informational value if they were supplemented by a range of non-economic development and sustainability indicators (e.g., quality of life statistics and ecological footprint measures) [28]. This having been said, the alternative economic indicators put forward in this paper appear to have a perfectly sound theoretical foundation [3]. Hence, rather than rejecting the indicators outright, more work should be undertaken to render them increasingly robust. Not only will this strengthen the conclusions drawn from them, it should make them increasingly useful to policy makers.

9 Conclusion

In this paper, I have argued that, to achieve sustainable development, a nation must embrace the notions of sufficiency, equity and natural capital maintenance. Whilst efficiency improvements resulting from technological advances allow for a desirable expansion of the macroeconomy (e.g., Figures 3 and 4), it is clear that the growth objective must eventually give way to an emphasis on sustainable qualitative improvement. Unfortunately, Australia is addicted to the growth objective and, as a consequence, appears to be violating all five behavioural modes put forward to achieve sustainable development.

Of course, recommending the abandonment of the growth objective to achieve sustainable development is one thing. Overcoming the political barriers to bring it about is another. Removing these and many other barriers constitutes an enormous challenge that will only be achieved if a viable alternative to growth can be successfully communicated – something that ecological economics, through the notion of sustainable qualitative improvement, is now offering.

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6 To understand what is meant by low and high entropy matter-energy, the importance of the first and second laws of thermodynamics must be revealed. The first law of thermodynamics is the *law of conservation of energy and matter*. It declares that energy and matter can never be created or destroyed. The second law is the so-called *Entropy Law*. It declares that whenever energy is used in physical transformation processes, the amount of usable or 'available' energy always declines. Whilst the first law ensures the maintenance of a given quantity of energy and matter, the Entropy Law determines what is usable. This is critical since it is not the total quantity of matter-energy that is of primary concern, but the amount that exists in a readily available form. The best way to illustrate the relevance of these two laws is to provide a simple example. Consider a piece of coal. When it is burned, the matter-energy embodied within the coal is transformed into heat and ash. Whilst the first law ensures the total amount of matter-energy in the heat and ashes equals that previously embodied in the piece of coal, the second law ensures the usable quantity of matter-energy does not. In other words, the dispersed heat and ashes can no longer be used in a way similar to the original piece of coal. To make matters worse, any attempt to reconcentrate the dispersed matter-energy, which requires the input of additional energy, results in more usable energy being expended than that reconcentrated. Hence, all physical transformation processes involve an irrevocable loss of available energy or what is sometimes referred to as a 'net entropy deficit'. This enables one to understand the use of the term *low entropy* and to distinguish it from *high entropy*. Low entropy refers to a highly ordered physical structure embodying energy and matter in a readily available form, such as a piece of coal. High entropy, conversely, refers to a highly disordered and degraded physical structure embodying energy and matter that is in an unavailable form, such as heat and ash. By definition, the matter-energy used in economic processes can be considered low entropy resources whereas unusable by-products can be considered high entropy wastes.

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