ENTROPY MAN

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Preface

The seeds for this book were sown in the 1970s, four decades ago, when I was then working as group economist for the engineering corporation Babcock International Plc. At that time the group employed about 30,000 people in subsidiaries spread all around the world, engaged in the design, manufacture and installation of capital plant for a variety of industries, including nuclear & conventional power generation, coal mining, gas, chemicals & petroleum, steel, automotive, cement, construction and environmental engineering. Prior to that, my formal university education had included a degree in engineering at University of Bath and a Masters in management science, allied to student sandwich experience with Amalgamated Power Engineering *[now a subsidiary of Rolls Royce]* and ASEA Brown Boveri, Switzerland, followed by working for SKF, the Swedish bearing manufacturer, often considered to be a bell-weather of world economic output.

From the 1980s onwards I worked as director of a consultancy, and subsequently also as an expert witness to the Courts, which roles I continue to the present day. These experiences have taught me to maintain an enquiring, dispassionate and impartial mind regarding the complex workings of human endeavour, the natural world and changes arising thereof.

My particular research interests in those early years concerned the parallels between the disciplines of economics and thermodynamics *[the science of energy & heat]* and how they relate to each other, as a result of which I published two peer-reviewed papers on the subject in *Energy Economics [1979 & 1982]*. Subsequent to these I gave presentations to international gatherings of government ministers, energy industry executives and academia.

Not being based at a university however, and with no research grant at my disposal, my main thrust had been to make a living from consultancy and therefore, until more recently, opportunities to spend time on research were few. Nevertheless, by the turn of the millennium I was able to find time to return to some research and published another peer-reviewed paper in the *International Journal of Exergy [2007]*, followed up by several working papers on monetary aspects and energy models. Subsequently in 2009 I wrote a technical book on the subject, to bring together all the facets of the work into a coherent whole: *'Thermoeconomics – a thermodynamic approach to economics'*. The book was subsequently revised, corrected and added to, up to a third edition *[2012]*, covering topics such as production and consumption processes, employment, money, interest rates and bonds, energy resources, climate change and sustainability, and including more up to date statistics. It has now been superseded by this book.

Whilst not being tied to a university, government agency, industrial enterprise or other organisation has disadvantages in terms of recognition and time available for research, it does nevertheless have the advantages of freedom to investigate and pursue a course of enquiry of one's own choosing and of drawing conclusions independent of those that pay the piper or who may have pre-set agendas, however well-intentioned these may be.

The nature of the subject requires significant proof for economists and scientists to accept that similarities between thermodynamic and economic phenomena might imply more than just a passing analogy or isomorphism, and relations between the two disciplines have rarely been comfortable, with scientists sometimes having scant regard for the work of economists; and many economists believing that science has little to offer their discipline which, by its nature, can be thought of as anthropocentric rather than eco-centric. One eminent energy scientist advised me that he did not know of an economist who could follow a thermodynamic argument. Certainly a concept such as entropy means very little to most economists, still less to the man in the street – money is their language of communication. The latter is not, however, the language that Nature and the environment converse in.

This book is intended for a mixed readership of scientists, economists and those of an enquiring mind. It is a challenge therefore to convey the nub of the argument in terms that all can appreciate, with particular reference to the effects of potential problems such as 'peak resources', humankind's effect on the ecosystem and the maelstrom that would ensue should resource failure or climate change ever come about to a significant degree.

While some chapters, notably chapters 4 through to 8, do contain some mathematical expressions, explanatory points are included to guide non-mathematicians onwards. Formal proofs and derivations have been relegated to the notes on each chapter.

Although economic man may currently have the ascendency, he does not actually *'own'* the Earth. He is there on sufferance, and the Earth would quickly forget him along the ecological timescale, should human civilisation fail or spoil the proceedings.

I am indebted to my wife Alison for all her support and for providing me with an atmosphere conducive to my research.

John Bryant

CHAPTER 12 ECONOMICS, ENTROPY AND A SUSTAINABLE WORLD

In the opening chapter it was highlighted that everything on Earth is subject to the Laws of Thermodynamics and the generation of entropy, and that we humans are no exception to this. Subsequent chapters developed the theme that human economic processes mimic the Laws of Thermodynamics in several ways: first when comparing economic flow to gas systems, second the similarity between the economic concept of utility and entropy generated out of consumption, and third, the structure of economic production and consumption process set against the workings of chemical thermodynamic processes. Economist Paul Samuelson drew attention to the subject, when he pointed to the Le Châtelier Principle and classical thermodynamics to explain the constrained maximisation problem, and although he did not live to proceed on to develop the notion of entropy his thought was certainly an intuitive one, well in advance of his time.

Economic expenditure on consumption involves the generation of entropy, and both individual humans and manufactured capital, through a lifetime of service, ultimately also degrade, entailing irreversible production of entropy. It's a fact of life.

One of the main conclusions of this book is that entropy production in an economic system can be equated to a logarithmic function of economic activity **V**, modified by the level of the constraints **X** acting upon it. Thus, in a similar presentation to the Boltzmann equation cited at the beginning of this book, economic entropy production can be enshrined as:

$$S = \ln\left(\frac{V}{X}\right)$$

Chapters 6 and 7, concerning money and employment set out some empirical evidence in support of this relationship with regard to the US and UK economies, and chapters 8 and 9 examined the dynamics of a non-renewable resource such as oil, with the proportion of reserves used to date equating to a gathering constraint. Other constraining forces could also impact on the above relationship, in particular those arising from outside the economic process, such as climate change and man's impact on the ecosystem and renewable resources, ultimately degrading the sustainability of natural capital.

Turning now to the neo-classical approach to economics; sustainability in an economic system in practice boils down to maximisation of utility, as a function of economic consumption and output, leading to the accumulation of manufactured capital owned by humans. In respect of natural capital, it is assumed that either it does not impose a constraint on human economic activity, or that unlimited substitution can be made between human-engineered capital and natural capital. Thus the only constraint placed upon economic consumers is that of a budget constraint – how much they have available to spend at any time – being dependent only upon human economic management. At first sight, therefore, it could be argued that maximising utility just follows the Laws of Thermodynamics, seeking to maximise entropy production through consumption of goods and services; with projections of the future being made on the basis of extensions of growth of the human populace and of manufactured capital alone.

This says nothing about potential constraints imposed by outside systems, however, such as resources or the environment, which may have a bearing on consumers' choices. It is just assumed that these can if necessary be replaced or circumvented over time by human ingenuity through the economic process, or be treated as one off 'external shocks'. A production function that included only humans and manufactured capital would be useless without resources, and a projection into the future would be meaningless.

To be fair, consideration of resource and environmental constraints has been a periodic, transient visitor to the economic world in the past, but which has eventually been shunted to the side-lines as humanity has found a way round. Peak oil in the USA has come and gone twice, and the green revolution has put off what many thought would be a limit to world food production. While a Malthusian would say that a finite world might, in the ultimate, impose potential constraints upon the level of activity of humankind, an optimist would place faith in human ingenuity in the process.

In 1972 the Club of Rome published the results of a dynamic feedback model of the global system *[Limits to Growth: Meadows, Randers et al – since updated to 2005]*, though this met with considerable resistance from the economic world at that time, and subsequently was largely put to one side as world economic activity continued unabated. More recently Sverdrup et al *[2011]* have devised a World Model 5 based on similar dynamic modelling principles, though it remains to be seen as to how seriously the economic world will take this. More work will likely need to be done, and on a broader and larger scale, if it is to have any impact at all on conventional economic wisdom.

If it is accepted that human driven economic systems seek to maximise entropy production in some manner, as do other Earth systems, then one might proceed further to consider the question of whether such a goal is consistent with sustainability of *both* economic and ecological systems. The evidence appears to indicate that the world is gradually moving from a position where the only constraints to economic growth have been those arising from human economic management, to a position where natural capital is progressively being seen as a potential constraint in the scheme of things. Moreover, because natural capital is complex and involves some long timescales, the current position has been developing for some time without humankind being generally aware of the situation.

Neo-classical economics is not able to cater for this change in affairs, primarily because it is built on the notion of a circular flow of value between labour and manufactured capital alone, with little or no recognition that true value ultimately comes from resources and from natural capital, albeit that humankind provides the intelligence and management to harvest and garner these treasures. This has meant that until recently ecological economics has been regarded overwhelmingly as a side issue to mainstream economic thought. A considerable shift in accepted wisdom is needed, away from a viewpoint that science has little or nothing to offer economics, towards structuring around disciplines incorporating terms and measures that relate to current accepted scientific understanding of the way the world works.

At a wider level humankind is only just beginning to comprehend how complex the eco-systems of planet Earth are, and what *Homo Economicus* may be doing to move them away from their equilibrium position, perhaps irrevocably. Numerous species of animate life are now threatened with decimation and some with extinction. Would Darwin, credited with the theory of evolution, have contemplated such a significant acceleration in extinction rates over such a short time?

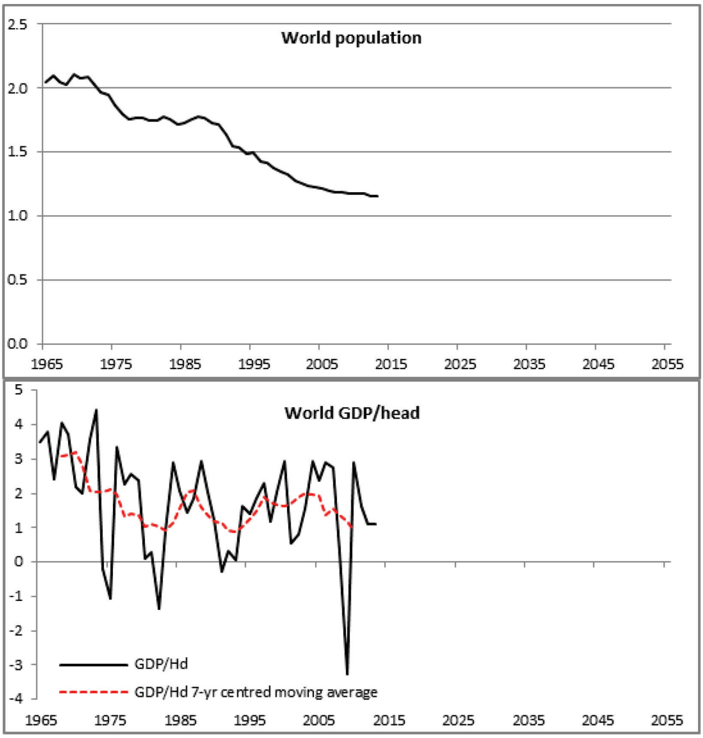
Perhaps the biggest constraint that now exists is the sheer size of the human population that has grown on the back of economic capital, based on the consumption of non-renewable and renewable resources. And here evidence is now coming to the fore that perhaps, unconsciously, humanity is beginning to acknowledge both its effect on the world system, and in reverse, the effect of the world system on humanity. Growth in the human population is beginning to slow down to the point at which it may eventually decline. While much of this could be pointed to dramatic improvements in healthcare, if resource availability and world ecological problems did not pose potential constraints, would not human population advance its horizon even further? The evidence suggests perhaps a more cautious view of the future, with 'peak humanity' on the horizon.

In respect of non-renewable resources, it would appear currently that peak oil has arrived, modified only by the impact of fracking in the USA. Peak coal may occur from the present to three decades away, with peak gas being up to three decades away. Nuclear power, under current technology, may have the same horizon. The production of metals and minerals, such as steel *[iron]*, cement, aluminium and others, vital to economic activity, is dependent upon the consumption of large amounts of non-renewable energy. On the other hand, one cannot discount entirely the possibility that further resource discoveries and technologies may come about to add to the remarkable developments of the last two centuries.

Turning now to renewable resources, a number of alarm bells are beginning to ring. Growth in world water withdrawals is beginning to slow down, and baseline water stress is rising significantly in particular areas of the world. The amount of arable land per head of population has been declining significantly, mostly owing to the rise in population. Soil erosion and degradation is on the increase, impacting on the residual amount of cropland available to grow crops. Despite these negative signs, food supply per capita worldwide is still increasing, particularly that of meat. That food supply has been able to grow, thus supporting population growth, has been owing to the green revolution, based on the use of irrigation, fertilisers and pesticides to increase yields. Fish production is still rising, though three-quarters of stocks are now regarded as being in the fully-exploited to depleted range. Other than hydro-electric power, renewable energy sources have yet to make a significant impact.

The world's food supply to humans via trade across land and oceans, however, is heavily dependent upon the consumption of non-renewable energy, in particular, oil. Without the latter, many people will have to find alternative, life changing, self-sufficient means of feeding themselves, leading to competition over land and associated resources.

All of the above leads the author to believe that tightening in the availability of resources is going to have a significant effect on future long-term growth in world GDP, even though the world energy/GDP intensity ratio is declining. On this basis growth in world economic output over the next few decades, and beyond, is going to be progressively harder and harder to obtain. The charts at figure 12.1 illustrate per cent growth in world population and GDP per head to the present time.



Data source: World Bank

Figure 12.1 Growth rates of world population and GDP per head. % p.a. 1965-2013.

On current trends there is a high level of probability that the growth rate in world human population will continue to decline, with population reaching around 9.2 billion by 2050, three and a half decades ahead. With regard to growth in world GDP per head, however, the future is much more difficult to predict, partly because of the large spread of change per year brought about by business cycle effects and factors such as energy upheavals.

Comparison with the chart of economic entropy change for the world oil industry at figure 9.10 for instance, reveals the same downturn points of 1973, 1980, 1990, 2000 and 2008.

Purely on a historical basis, a trend line for GDP/head from about 1980 to 2013 would suggest an average compound, exponential rate of 1.4% p.a., achieving a doubling of world GDP by 2050. Some of the model growth rates for GDP/head assumed by IPCC are much higher than this however, projecting a level of GDP by 2050 in a range up to 4 times the current level and much higher by 2100.

Set against these figures, however, are the trends in resource markets, alluded to earlier, and discussed in chapters 9 and 10, which might lead one to expect a declining trend in growth of output per head over the next three and a half decades, should resource availability flatten off further. A trend line from 1965 onwards for instance, would suggest a declining rate, approaching zero growth in world GDP per capita by 2050, with some countries above this and some below.

Perversely, given the amount of airing that the advent of climate change has received, for a world where GDP per capita growth has subsequently declined over a few decades to a low or even a negative level, then growth in the amount of greenhouse gases released annually to the atmosphere might be expected to slow, perhaps at some time in the future effecting a reduction in the present rate of increase in temperature. Nevertheless, some aspects of climate change seem likely to persist, entailing reductions in economic activity for some vulnerable areas in the world, and involving movements in populace, civil and political unrest and some write-offs of both human-engineered and natural capital. On the other hand, economic man might endeavour to continue efforts to expand output, adding pressure to climate change.

Significant variations exist regarding individual per capita economic wealth, both at international and national levels. Just ten countries account for 35% of world GDP, but only 13% of world population *[source: World Bank]*. It is a matter of evidence as to the geographic source of the resources funding this economic wealth. Japan for example has few natural resources, yet has managed in the second half of the 20th century to build an economy based on processing resource value imported from elsewhere, such as metal ores and energy, combined with technology know-how.

It can be readily appreciated, therefore, that those with a ‘poorer’ lot might aspire to catch up with those more fortunate, particularly if economic and technology tools are at hand to facilitate this. In the more recent past both China and India, with very large burgeoning populations, have grasped the genie that economics has offered developed economies, and are setting about becoming the manufacturing hub of the world. This involves consuming increasingly large amounts of energy and other resources. Currently these areas of the world have higher economic growth rates than those of the developed countries, though it remains to be seen as to the effect that potential resource limitations and degradation might have in the future.

From the development in this book, it was shown that the notion of utility in an economic sense is closely related to that of entropy, and that maximising potential entropy production is consistent with both natural processes and those arising in ‘man-made’ economic systems. A formal link between output flow and maximisation of potential entropy production can only be established however if account is taken of constraints acting upon economic systems. These constraints take the form of factors that can affect flow of output; not just a budget constraint, but specific factors that can influence whether output goes up or down. Factors identified in this book include not only traditional economic ones such as money supply, production capacity and employment, but those involving natural capital, such as resource constraints – both renewable and non-renewable – and those constraints arising from the eco-system such as climate change.

From a thermodynamic viewpoint a process is more sustainable if less harmful losses of useful energy/productive content occur. This is more likely for a renewable resource, as losses generated from consumption can gradually be replaced by those of new resources entering the flow, nurtured by Nature and the Sun. However the position with a renewable resource is not guaranteed, for if over time the rate of usage inclusive of Second Law losses is greater than the rate of replacement, it is likely that the resource will gradually reduce in size, in the manner of a non-renewable resource. Strong sustainability on a thermodynamic basis therefore will only be achieved if humankind just abstracts value that can be fully replaced by the Sun, through the interlinking eco-systems and subsystems humankind relate to, such that future generations of humanity and life on Earth can prosper in sustainable harmony, without the ecological system being compromised.

For example, draining marine life from some oceanic areas *[including removing seabed life via trawling]* to a level where the stock biomass has negative marginal growth affects reproduction, with an ensuing decline in stock levels, which may also affect other higher and lower level species in the aquatic system. It follows that if the human population continues to grow alongside a declining marine stock, then at some point particular oceanic areas could become barren and reduce their support to human life and other living forms.

The same logic follows regarding the use of land to grow food and nurture farm animals. Consuming even more energy to produce fertilisers may improve yields, but forever reducing arable land and degrading soils in favour of production of consumptive products is a negative a factor. No amount of exponential projection of human GDP will restore the base on which food is grown. The net effect of a global policy that followed the weak sustainability path is that irretrievable natural resource depletion and ecosystem damage could escalate to a position where global constraints might force a retrenchment, if not something much more serious.

All of the above suggests that the key path to promoting strong sustainability may not be by humankind burning its way out by producing more GDP to feed its growing population in the hope that technology will solve the problem, but by consuming less. It is however quite contrary to human nature to reduce voluntarily an appetite for more, if not faced with an immediate constraint, and it is unlikely that individual nations and people would be willing to give up their way of living to the benefit of others unless, by international agreement and enforcement of such an agreement, each may be persuaded to reduce consumption if all suffer together. To date, international agreements on climate change policy, destruction of rainforests and harvesting of the oceans have not so far resulted in a significant change from the path of 'same as usual'.

Even if action were taken, it is human nature *[the entropy maximisation principle again]* that humankind having made a saving in one direction, would wish to go out and use the saving for something else. Thus just reducing expenditure on a non-renewable form of energy to replace it with another 'sustainable' form may leave GDP proceeding apace, but the threat of more population and short-term consumption of other resources such as food and potential overloading of the eco-system would remain.

In times past, the most effective occurrences that have persuaded both governments and populace to pull together to solve a problem have been in times of war and of recession/depression with reduced income. These were times when the populace experienced ‘real’ pain from a constraint or force, as opposed to being told that a ‘threat’ of pain might occur in some period ahead.

Human actions to ensure a high level of strong sustainability rest on the populace of all countries taking a much longer term view than hitherto has been the case, based on continued review and research into links between human and ecological systems. Nevertheless the advent of modern communications has meant that most people in the world are by now aware of the problem, even if singly and collectively they have so far done little to change their ways. Ingenuity and thought may play a part in the solution, but technology on it own will not provide an answer.

All this suggests that possibly a more likely outcome in the decades to come is eventually some reduced sustainability of natural capital, affecting carrying capacity, with an associated effect on human activity, a levelling out or even a decline in population and, over time, adjustment of economic output to levels commensurate with prevailing constraints.