ENTROPY MAN

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Preface

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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 5 PRODUCTION AND CONSUMPTION

Production and consumption in economics are about the means by which human needs are met; expressed in monetary terms at the aggregate level by the GDP, which can be defined in terms of income *[wages, profits, investment income]*, expenditure *[durables, non-durables, services, residential structures, machinery]* or by major output sectors *[agriculture, mining, energy, construction, manufacturing, services]*. These expressions do not however describe the dynamic process of how an economy works or interacts with Nature and the environment, only its overall structure and content.

The traditional economic picture of how the long-run production process works is built on the theory of the firm, in terms of production functions and marginal productivity equations. The production function is formulated as a technical relation between outputs and inputs, the latter principally arising from capital and human labour stocks. Functions can also be added or considered alongside, to take account of re-investment in capital stocks, technical progress and the elasticity of substitution between capital and labour; and efforts are also made to estimate the output gap *[the difference between actual and theoretical maximum output]* as a function of changes in capital stocks and the labour supply. The following expression is a simple form of the well-known Cobb-Douglas production function *[Cobb, Douglas (1928)]* with a Hicks-neutral technical progress function added *[Hicks, J. (1932)]*:

$$V_O = Ae^{\lambda t}(N_K)^{\alpha}(N_L)^{\beta}$$

Where $\mathbf{V_O}$ is output volume flow, **A** is a factor incorporating output usage per unit of time per the complex of stocks, the exponential function represents technical progress over time **t**, $\mathbf{N_K}$ and $\mathbf{N_L}$ represent capital and labour stocks *[in volume terms]*, and the indices $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are output elasticity coefficients signifying:

$(\alpha + \beta) < 1$	*Decreasing returns to scale*
$(\alpha + \beta) = 1$	*Constant returns to scale*
$(\alpha + \beta) > 1$	*Increasing returns to scale*

The expression is forward looking, effectively projecting exponential growth into the future and, with no consideration of constraints that may halt the process, does not take account of short-term variations. Economists tend to take for granted that resources and energy are used up in the process, and consequently indices $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are identified with the marginal productivities of capital and labour alone, as measured by the share of capital costs and wages to the value of output. All other factors are assumed to impact via technical progress.

Economists assess the short timescale economic climate by reference to model-based analyses combined with statistical trend analyses of relevant indicators such as prices, output, employment, savings, interest rates, external trade, and business and consumer sentiment. More recent developments include New Keynesian dynamic stochastic general equilibrium models, which view the economy as a whole, based on the interaction of many microeconomic decisions and the effects of random shocks.

A scientist would regard the economic approach to production as contravening the Laws of Thermodynamics. Heat can only flow from a hotter body to a cooler body, and the factors providing the heat and energy input are mostly the productive content of the resources, with some capital and labour stock consumption, which in turn create product, net of an efficiency factor, with an associated release of entropy to the environment. In the traditional economic Cobb Douglas formula, if there were no resources, then output could still be projected forward exponentially into the future, which clearly would be a nonsense.

Ayres, Kümmel et al have shown *[through a LINEX function]* that traditional economic theory explains very little of growth compared to factors such as natural resource energy. They calculate that, over a 100-year period, contrary to the traditional view of productivity being two-thirds down to labour, with most of the rest taken up by capital and only a small proportion arising from energy, the roles of labour and energy are in fact reversed, with two-thirds of productivity coming from energy *[measured as exergy or useful work]* and only a small input from labour, with the most important factor influencing technical progress being that of improvements in the efficiency of which fuels are converted into useful forms of work, with perhaps a more recent input from information technology.

As noted at chapter 4, economic systems have elements of *both* flow and non-flow processes, they are not just one or the other, as in a thermodynamic gas system. Productive content flows in and out of capital, labour and resource stocks, such stocks having variable lifetime lengths and degrees of both renewability and level of activity in the process. Production capital plant wears out over a number of years as its usefulness is consumed in the production process, but it can be replaced by investment *[arising from* *output]*, and be augmented by technical progress. It may not always be operated at full output potential. Likewise, human work contribution to the production process is spread over a lifetime, and which is renewed by the birth/education process. It too does not always operate at full capacity, giving rise to varying levels of unemployment and economic inactivity. Resources can be divided into those that are renewable and having an extendable lifetime, or non-renewable with a gradually reducing lifetime. Their activity levels *[for human requirements]* can vary also.

Output from a specific production process automatically becomes *input consumption* to another production process, such as intermediate production, and then on to final consumption expenditure or to the production of humans and capital stock, or of waste. Ultimately all output is consumed or degraded over a period of time, even humans and capital stock.

A Simple Production System

Imagine initially a production system involving a *fixed* process. By this is meant that to produce a particular product, specific amounts of the productive content of particular types of capital, labour and resources *[including energy – fossil, sunlight et al]* are required, and no other combination, and which are consumed together via the specified production process. It is easy to imagine inputs of resources and materials; numbers of nuts and bolts, grams of a particular type of chemical, watts of electricity, weight of grain. More subtle is the amount of productive content of capital stock *[gross/scrap or net/depreciation bases]* and human labour used up in the process. In this fixed system, substitutes that entail a different combination are excluded, as are also changes in design or method of production.

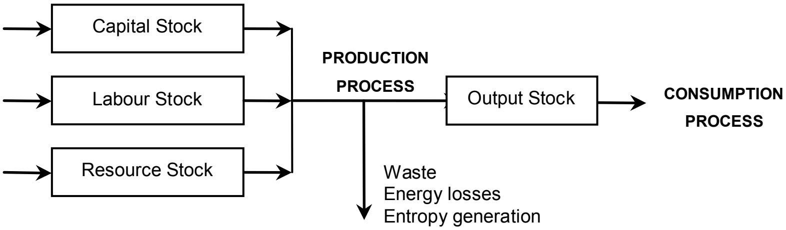

Figure 5.1 A Simple Production System.

Input volume flows of energy and materials into the production process arise either from resource stocks and flows within an economy, or are imported from those of an external economy.

In our fixed production system, imagine for the sake of argument that we are possessed of a homogeneous scale of productive content across all types of inputs and outputs *[which scale of course does not exist in real life]*, whereby to form one unit of a particular output product **O** over a specific time interval *[a rate of production]*, requires consumption of **α** units of capital plant **K**, **β** units of labour **L** and **δ** units of resource(s) **R** over the same time interval *[We could add other factors to the process, such as creativity and management, but will not complicate the issue here]*. Although the inputs are all different in nature and their productive content may be defined in different ways, this does not stop the process of combining them together, and our *imaginary* homogeneous scale is therefore introduced to enable them to be defined on a common basis and combined together. Thence we could write out a relationship not unlike that for gas/chemical reactions, set out in chapter 1, and with a two-way sign inserted to show that the forward process level could vary:

$$\alpha K + \beta L + \delta R \rightleftharpoons 1O$$

In gas/chemical reactions fixed arrangements are normal, there being only one configuration of inputs and outputs; for example, two molecules of carbon monoxide combust with one molecule of oxygen to form two molecules of carbon dioxide; there is no other combination.

An economic production system, however, has two key differences compared to a chemical one, first that the process is forward moving only *[though the volume flow can go up or down]*, and second, that in order to make a product, resources have to be *fashioned* in some way, and thereby some waste product is produced; scrap metal is produced when a piece of steel is machined, remnants of cloth are produced when cloth is cut to make clothes, waste heat goes up a chimney when electricity is produced in a fossil-fired power station, or through the walls and windows of a house. Waste products have low productive content and high entropy value compared to the inputs and the product output, though advanced production systems are designed to minimise the loss as far as is practical. In fact waste efficiency losses occur at each production stage, from Nature all the way to final output, and the consumer pays for the cumulative losses of all these stages via the product price.

Warr et al indicate that while aggregate fuel exergy conversion to useful work in the UK has risen from about 5% in 1900 to about 15% in 2000, this still leaves an 85% loss. In this book, therefore, the efficiency loss of useful work is presented as a separate product item **D**, to enable the Euler exponents to be set out, though an alternative would be to replace to the waste item **D** by an entropy function $\mathbf{S_D}$ feeding to the surroundings/waste reservoir.

$$\alpha K + \beta L + \delta R \rightleftharpoons 1O + \rho D$$

The diagram at figure 5.2 shows the effects of the production process. An entropy rise occurs as the capital/labour/resource combination is consumed, creating an 'ordered' product with low entropy. The product is subsequently consumed over time, creating a matching entropy rise. Ultimately, all economic output, through consumption, creates entropy.

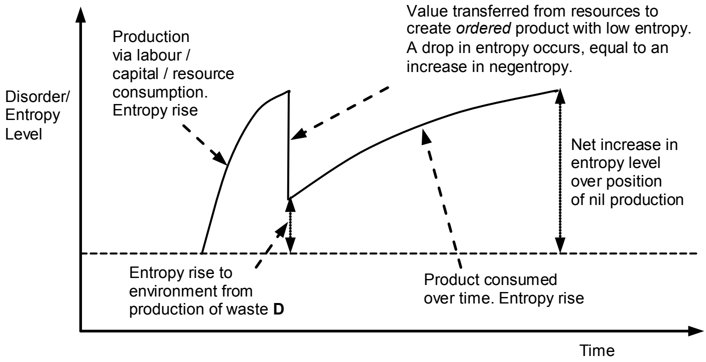

Figure 5.2 Product Order/Disorder and Entropy over time.

As set out at the beginning of this book, the thermo-economic approach is based on the Le Châtelier Principle. It is not asserted that systems do attain equilibrium, only that they continually seek to proceed to such positions. Our system therefore is a non-equilibrium dynamic one, by definition. However, as noted at chapter 3, macro-economic accounts automatically assume that the position is balanced in money terms; the values of output, income and expenditure all match each other *[bar any net trade – we are accepting that this is a somewhat simplistic view of an economic system]*. So where is the non-equilibrium motive force which drives the system to change?

As a first step towards a solution it is necessary to redefine volume flows. Suppose we separate out each stock component into the part that is currently *active* and the part that is currently *inactive*, that is, *not* contributing to the production process flow, as in the diagram at figure 5.3. The concept of *activity [symbol **a**]* is common in chemical thermodynamics and is a measure of the effective concentration of a species in a mixture. In general it is dimensionless with a maximum value of unity *[1.00]*. In an economic context, increased *activity* rates could arise from greater use of immediate capital, labour and resource stocks, or from those stocks further back in the chain, but depending also upon the degree of stock renewability and the ultimate full activity rate possible. Likewise going forwards, it is possible that demand to replace or augment consumer stocks might change. We could represent the active stock $\mathbf{N_a}$ as a proportion $\boldsymbol{a}$ of the total stock $\mathbf{N_T}$. Thus $\mathbf{N_a} = \boldsymbol{a}\mathbf{N_T}$. Likewise the inactive stock $\mathbf{N_i}$ would be expressed as $\mathbf{N_i} = \mathbf{(1-}\boldsymbol{a}\mathbf{)N_T}$.

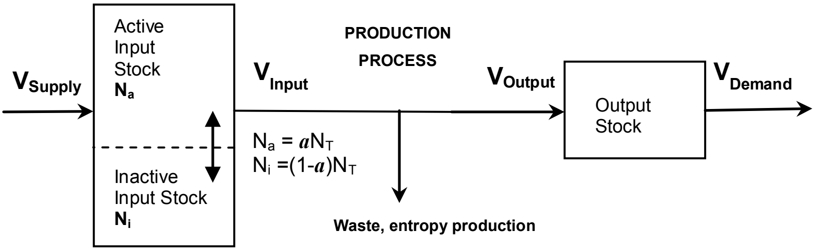

Figure 5.3 Active – Inactive Components of Economic Flow.

Further, volume flow **V** could be represented as:

$$V = vN_a \quad \text{or} \quad V = vaN_T$$

Where **v** is the volume flow rate per unit of stock, and $\boldsymbol{a}$ is the activity level.

An example would be the actual output flow produced and contributed by *active* employed labour, but offset by the *potential* output that might otherwise be generated by the remaining *inactive* labour that is currently unemployed or economically inactive, and which *absorbs* value from the system *[unemployment benefit]* rather than creates it. If there is a demand for increased output, then there are additional units of labour available to fill the productive gap, and vice-versa. Likewise it is reasonable to posit that the generation of profit is more likely to be enhanced if all of the producer capital stock is utilised at all times and with no 'down-time' when it is unused. In the case of a money stock or total debt, servicing the output and consumption flows of a whole economy, a reduced or enhanced level of utilisation could be engendered by changes in interest rates. Thus far, the shape of our system has some similarities to the economic concept of the output gap, alluded to at the beginning of the chapter.

In the case of a resource stock, although at a macro level it does not appear in national accounts, except as a value flow attributed to wages and profit, or added value output gross of efficiency losses, it does nevertheless exhibit properties of utilisation, in that the extent to which the production and consumption flow rates could increase or decrease will be influenced by levels of demand, renewability, depletion and discoveries, and by intervention of human decision makers. Examples of course include world oil, gas and other markets. Similarly, in reverse to a resource stock, we could also imagine a waste stock, the size or impact of which might influence the level of output flow from an economic process, via pollution or other effect from the environment and the ecosystem. Finally, we could imagine that a flow of product to an output or consumer stock might occasion an increase in saturation or *inactivity* of that stock, unless it was depleted by factors of depreciation, consumption, obsolescence, or sales to a buyer.

Now we consider some volume flows of reactants of capital plant, labour and resources, which feed output production at initial equilibrium steady flow levels of defined *activity* levels; that is, the proportions of each of the input stocks that are actively contributing to output production, these proportions not necessarily being the same for each reactant factor. Imagine that the system is then provided with an additional *motive force of anticipated benefits* potentially to encourage the flow rate of output, such that the level of output can rise to another level appropriate to the motive force, as depicted in the upper chart at figure 5.4.

Such a rise may be met by increasing the *activity* levels of one or more of the input flows/stocks and reducing their *inactivity* levels. What levels they actually each reach, however, will depend *both* upon the ultimate demand for output flow, which relates to systems forward of our system, *and* the inactive availabilities of each of the input flows/stocks. The upper chart at figure 5.4 illustrates the movement of the individual factors over time to reach the new equilibrium level. We could however equally consider a position where the *motive force* might be such as to discourage the flow rate of output, in which case the *activity* levels of the inputs would fall and their *inactivity* levels would rise, as in the lower chart.

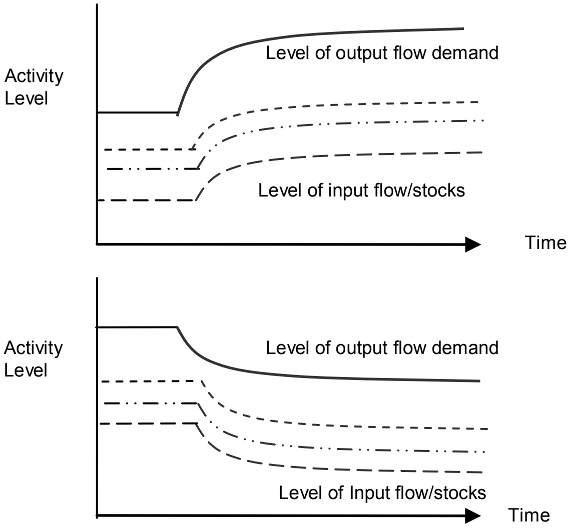

Figure 5.4 Activity Levels in a Simple Production Flow Process.

Further activity effects could also be considered: that of the stock to which output flow proceeds towards, which may be within the system *[as in an output stock]* or may be outside the system *[as with a customer/receiving agent, or the input stock to another process]*, and likewise a stock further back in the chain supplying our system.

It is plain that the ultimate flow level reached will be fixed by which of the input and output flows constitutes the major limiting factor. An input factor that was already fully active could not support a rise in output and would become the dominant restraining force at that moment in time; it is not axiomatic that input and output flows will rise in tandem with each other. Potential restrictions might be particularly prevalent in one or more of the factors, compared to the others, and impact at different times to the others, as the economic system proceeds. For example, the availability of labour might be restricted; a particular material might be in short supply; a restriction might exist with regard to the creation of additional waste, or the level of financing costs to fund an increase in demand and output flow, in terms of interest payments, might subtract from fully increasing production.

In order to represent the impact of a motive force initiating increased or decreased volume flow rates of capital stock, labour and resources and converted into a changed product flow rate, resort is made to the concept of

Free Energy, famously pioneered by J Willard Gibbs *[US mathematical physicist (1839-1903)]* and Herman von Helmholtz *[German physicist (1821–1894)]*. It expresses the total amount of available or 'free' energy which can be used up during a reaction to equilibrium. For the purposes of this book, the particular variant of *free energy* applied to economic systems is that of *chemical potential* $\boldsymbol{\mu}$, as expressed in *volume* terms in the following equation:

$$\mu = \mu^{std} - NkT\ln(V)$$

Free value for a chemical system is equated to a standard state value $\boldsymbol{\mu}^{\mathbf{std}}$ and a logarithmic function of the volume **V**. The expression can also be set in terms of an activity rate $\boldsymbol{a}$ *[as in a chemical solution]*. The standard state value $\boldsymbol{\mu}^{\mathbf{std}}$ is derived by experiment according to specific states of temperature and pressure for particular elements and compounds acting in solution, whereby the proportions of the compounds are in equilibrium with each other. The function **NkT** relates to the familiar factors of number of molecules, the Boltzmann constant and the temperature. The activity factor $\boldsymbol{a}$ of a compound is generally calculated by reference to its concentration in a solution.

Reverting to the economic presentation, the free value of an economic component that is available to combine with other factors to form output could be defined in a similar way, but either on a *volume flow* basis or on a *stock activity rate* basis, depending upon the relevance of each to the system being considered *[see the chart at figure 5.2]*. As noted earlier in this book, the factor **k** becomes 1 in an economic system.

$$\mu = \mu^{std} - NT\ln(V)$$
$$\mu = \mu^{std} - NT\ln(a)$$

Where **N** is the stock number and **T** is the index of trading value.

The procedure is to add up all the *free values [instead of energies]* for the outputs, and likewise those for the inputs, recognising that to form a product the components have to combine in a ratio according to the Euler exponents set out earlier for the modified Cobb Douglas function. Thus net free value available to promote the forward reaction is equal to the difference between these two:

$$\textit{Net free value available} = 1[\mu]_O + \rho[\mu]_D - \alpha[\mu]_K - \beta[\mu]_L - \delta[\mu]_R$$

Mathematically speaking, one then substitutes in the free value functions for all the factors in the equation; recognising that it is the *inactive* input components that are combining together, thus becoming active, to form output. Thus, for an increased forward reaction, the inactivity of inputs is reduced and their activity is increased *[if there is capacity to do so]*. An essential point to make, however, is that economic systems are heavily interconnected with each other, such that many tend to go up or down together with perceived demand, though there may be time lags between changes, as illustrated in figure 5.4.

Two further points should be noted. First, in an economic system the components combine together through a common denominator called money. This fact enables a simplification to be made to the mathematical process. And second, as with free energy, change in free value **Δμ** can be expressed in terms of the negative of entropy change **–TΔS**. For a forward reaction for example, as with a growing economy, change in free value is generally *negative* and change in the entropy production rate is *positive.*

The following expressions set out end relationships between changes in output volume flow and changes in either the input factor volume flow or the activity level of stocks, and of a dynamic *system* entropy function *[the latter being separate from entropy arising from consumption of output and through generation of waste]*. The formal derivation, along with the assumptions made, is set out in the notes to the chapter.

$$\left(\frac{V_2}{V_1}\right)_{Outputdemand} = \left[e^{(S_2-S_1)}\right]\left(\frac{V_2}{V_1}\right)_K^{\alpha}\left(\frac{V_2}{V_1}\right)_L^{\beta}\left(\frac{V_2}{V_1}\right)_R^{\delta}\left(\frac{V_2}{V_1}\right)_D^{-\rho}$$

$$\left(\frac{V_2}{V_1}\right)_{Outputdemand} = \left[e^{(S_2-S_1)}\right]\left(\frac{a_2}{a_1}\right)_K^{\alpha}\left(\frac{a_2}{a_1}\right)_L^{\beta}\left(\frac{a_2}{a_1}\right)_R^{\delta}\left(\frac{a_2}{a_1}\right)_D^{-\rho}$$

Change in demand to consume more of output production between two states is equated to changes in the factors of production, modified by change in the system entropy factor. Should demand to consume more of production output increase, the entropy change becomes positive to balance the equation. The production function of capital, labour and resources endeavours to rise to the new level demanded, until the system entropy change becomes zero. The extent to which this occurs depends upon the constraints impacting upon the system.

The above production function has similarities to that defined in the Arrhenius equation *[Swedish scientist Svante Arrhenius (1859-1927)]* and the Eyring equation *[American scientist Henry Eyring (1901-1981)]*, which are expressions used in chemical kinetics to link the rate of reaction to the concentrations of the reactants.

The relationship also has a similarity to the familiar Cobb Douglas production function used by economists, as set out at the beginning of this chapter. There are some key differences however:

1. *A system entropy function is introduced, which determines whether increased or decreased flow arises. An economic system out of equilibrium will seek an equilibrium flow rate such as to maximise its level of entropy generation per unit of time in line with prevailing constraints, when no further change in the rate of entropy production occurs.*

2. *The system entropy function described is separate from entropy generation delivered to the surroundings, arising from the consumption of input and output flow, or from the generation of the waste. However, should a rise in system entropy, engendered by a rise in demand, be met by a rise in input and output volumes, such that the change in system entropy becomes zero, then the original system entropy difference has been transferred to that relating to flow of input and output consumption and of waste production delivered to the surroundings.*

3. *Elasticity coefficients are expressed in real factor terms, and do not assume labour to be pre-eminent. A means of deriving these is required, compared to those assumed by current economic theory.*

4. *A separate technical progress function is not required. Instead technical progress arises from changes in the mix of inputs, in particular the use of energy and capital stock technology to replace human work. This involves the development of different relationships in the production function.*

5. *Each factor input has its own cycle of renewal and replacement, the time length of which might be different to the others, which will impact on the*

relative strength of any constraint over time. Thus changes to one might have longer or shorter effects compared to the others such as to make it the dominant factor in the proceedings.

6. *No assumption about the shape of forward growth or decline is made; the position is a continual dynamic feedback situation, whereby a position of equilibrium is at best a fleeting moment.*

In summary, in an economic system, change in the *active* output flow rate demanded is expressed in terms of a system entropy function and of change of flow of the components available to combine together. A restriction in any particular reactant can affect the forward rate, and likewise, abundance of the same reactant will place weight on the other reactants to be potential constraints on output flow. For example high availability of *inactive* resources such as energy and food resources will encourage growth in employment and investment in producer capital plant.

The dynamic nature of the analysis becomes apparent when the process is joined up with all the other adjacent interacting systems, and likewise they in turn are linked up with more distant systems. Thus capital stock depreciates and is replaced by new investment, labour retires and is replaced by recruitment of new personnel, and resource stocks are replenished by reordering. If one reactant is used up - for example, product **O** is sold on to the next system - then the system produces more **O**. Likewise as a resource **R** is used up, it is replaced from another system, which perceives demand for its product, and so the reaction goes on. We have derived an inter-reacting trading process, with free value continually being used up by one system and replaced by that of another, and economic entropy generation arising. If a particular constraint has an effect on a connecting system or one further up or down the line, then a chain reaction reflecting that constraint might occur.

The nature of the thermodynamic exposition indicates that output is a complex, non-equilibrium function of stocks and flows, with elements of systems dynamics, with an equilibrium position that is continually varying, and that production and consumption processes are structured to seek to maximise entropy production subject to changes in the constraints.

Growth and change in an economic system over the long term depends on the availability of resources to fuel the process and the ability of the ecosystem to absorb the residual waste and heat. Exponential growth is not axiomatic.

From all of the above, in general terms entropy production **S** in an economic system can be equated to a logarithmic function of volume 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, entropy production could be expressed as:

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

The March of Entropy

Imagine a man of the country living in the open, away from 'advanced' civilisation. He decides to build a house from local materials, to improve his well-being and provide shelter from the elements. So he corrals together all the materials he needs, being locally in plentiful supply, along with tools he has to hand, and builds the house, expending physical energy and consuming inputs to create something lasting. He has just ordered things for his benefit. Buildings, being what they are however, gradually fall into disrepair *[disorder]*, unless given some love and attention, and in the ultimate, if left for sufficient time, decay and fall down, losing all their use value over the time, with an associated production of entropy. There are few remains and relics of former ages of man.

The argument might be put nevertheless that doesn't the order in the house generated by the man compensate for the disorder outside? After all, if the man looked far enough away from his place of living, he would find that the world is full of living things, humans and the trappings of mankind, which are all highly ordered entities.

The simple answer to this is no, for in order to create an initial ordered state with a low entropy level, according to the Laws of Thermodynamics, additional energy gradient has to be consumed to increase the order level than is actually transferred to and contained in the increase in order. In other words, some value is downgraded and thrown away that cannot be retrieved, with a net increase in entropy. Man is not alone in this phenomenon – as was shown in chapter 1 – the whole of Nature operates in this way.

The diagram at figure 5.2 earlier in this chapter summarises the entropy changes involved in building and 'consuming' the house:

At the production stage, a part of the man's efforts and the resources he uses is transferred to the product – his house – involving an increase in 'order' and a decrease in entropy. The other part appears as waste *[sweat, discarded materials etc.]* accompanied by a rise in entropy to the environment. Through the life of the house, however, a further rise in entropy to the environment occurs as the house decays, arising from wear and tear and the forces of Nature. Should the man decide to rebuild the house, then the whole process begins again, but starting at the level finished at after the demise of the first house, and so on. Figure 5.5 illustrates the principle, assuming continuing processes of demise and rebuilding.

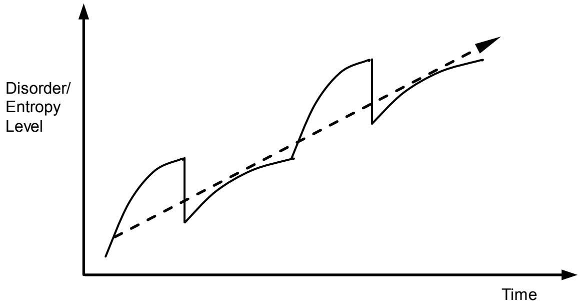

Figure 5.5 Advancing Entropy.

Entropy increases cumulatively over time. A similar picture emerges if instead the man chooses to repair the house periodically.

Now we imagine a man in a 'modern' society commanding significant wealth, where energy and resources are plentiful and technology is developing fast. Such a man, instead of having to work physically all the hours of the day, is now able to benefit from the value of resources and energy to do the work, and become an overseer of the process. Production efficiency losses continue to occur, giving rise to waste and a release of entropy to the environment.

The discovery of energy and resource availability enables our man to increase his consumption, to the point at which he might indulge in throwing away some of his assets much before the end of their lives, in favour of purchasing new more 'up-to-date' assets to replace or augment what he already has – the 'throwaway society' or planned obsolescence. The chart at figure 5.5 then changes to that in figure 5.6, with product consumption being curtailed before the end of its life and replaced by consumption of new products. The rate of entropy production grows faster, but of course is dependent upon a continuing supply of energy and value to fuel the process.

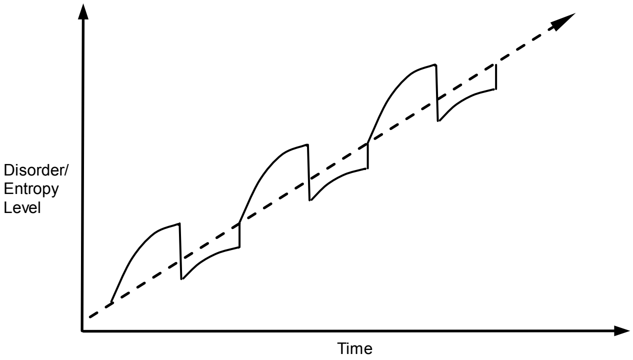

Figure 5.6 Entropy Growth in a Throwaway Society.

There is nothing wrong with the creation of entropy from consumption and resources – it is the way the world and Nature works. Plant life and grazing animals follow a similar process, continually seeking out the shortest route in terms of time to a source of water and nutrient energy, but if this subsequently dries up or is not renewed by Nature and the natural cycle, they spread their net further to seek other sources. If there are no further reachable resources they will eventually wither and die. Effectively life endeavours to follow a path of maximum entropy production, choosing the first available path in terms of time that does this, but if this subsequently proves not to be fruitful or provide further opportunities, it seeks to choose another path.

In the ultimate, human life also follows such a process, though humans, with a higher level of gene and intelligence, are able to make use of the resources that the Earth has to offer in a manner, quantity and speed that no other *[Earthly]* species can match, and can also consider longer timescales. More recently in the ecological timescale, humankind has developed from requiring only basic food, shelter and breeding/germination, as other animals and living organisms, to engineering a significant diversion of Nature's resources to fulfil particular and developing desires not strictly necessary for the preservation of the species. A further consequence has been the mushrooming of the human population and its consumptive, entropic manner of living compared to some other species.

Drawing together the threads between economics and thermodynamics, we can see that the underlying principle or algorithm is one of maximisation of potential entropy production. Decisions that are favoured include:

- *Pursuing positions where the activity rates of inactive inputs can be increased easily and with minimum cost.*

- *Investment in economic structure to change the system to supplant/replace a constraining component with higher net yielding output; for example, power from energy sources replacing manpower.*

- *An emphasis on shorter term projects compared to longer term ones, as the quality of information concerning the future decreases with time.*

The impact of this process, back up by some empirical analysis, will be examined in later chapters.