JOHN CONSTABLE

Energy, Entropy and the Theory of Wealth

Delivered on 11 February 2016, as part of Newcastle University's "Insight" series of public lectures

Northumberland & Newcastle Society

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INTRODUCTION

I am very pleased to be introducing this paper which was jointly organised with the Newcastle University Insights Programme of Public Lectures and we thank Newcastle University for kindly facilitating this event.

The Northumberland & Newcastle Society was formed in 1924. It has been campaigning and exploring issues which have affected the environmental context of economic development in the north east of England during that period. For over 90 years the Society has examined, amongst other issues, the influence of electricity, nuclear power, water, coal and, more recently, wind power on our environment. We have considered the extraction and infrastructure of these sources of power, the effects they have had on our landscape and the impact these developments have had on the regional economy.

John Constable's talk is very relevant today as the government is exploring the political influence of redefining the role of the region within the national economy. Through discussion of the Northern Powerhouse, the government is attempting to refocus and stimulate economic activity in the north east of England and bring greater social development and wealth to the area.

The north east has been a cauldron of invention for the development of energy sources since the nineteenth and twentieth centuries. Coal, electricity, nuclear and wind power sources have underpinned the economic outcome of developments in the north east of England and the associated technical and industrial innovations which have evolved during this time.

We have seen the extraction of coal and the development of heavy industrial processes for the production of steel and chemical raw materials evolve into the more recent emphasis on the manufacture of pharmaceutical and consumer products. Most recently we have been actively engaged with Northumberland County Council planning department, proposing amendments to their policy statement on renewable energy and, in particular, the criteria for granting planning consents for wind turbines.

Therefore, it was an appropriate moment to be able to ask John Constable to deliver his thought-provoking lecture, 'Energy, Entropy and the Theory of Wealth', in which he discusses some of these issues. His timely analysis of energy sources and their conversion into mechanical work links their relationship to the creation of wealth and gives us a challenging vision of 'high-energy environmentalism'.

Our members have much to consider as we move forward with the programme of questions which we want to put to our administrative and political leaders and thereby fulfil our mission statement: 'Working together to protect and enhance our landscape, built environment and cultural heritage'. We are concerned not only about the physical characteristics of our environment but also want to ask questions in order to challenge the intellectual basis of these policies. We need to better understand the forces and relationship between our resources and their development, and what determines economic success through the creation of wealth.

Dr Geoffrey Purves
Chairman, The Northumberland & Newcastle Society
1 June 2016

ENERGY, ENTROPY AND THE THEORY OF WEALTH

Firstly, my thanks to Newcastle University and to the Northumberland and Newcastle Society for the kind invitation to speak to you today.

By the end of the talk I hope that I will have refined and given much more substance to your ideas about energy, wealth, and their history, so that when you look at chart like this, representing world Gross Domestic Product from 1 AD to 2003 AD, you do so with fresh eyes.

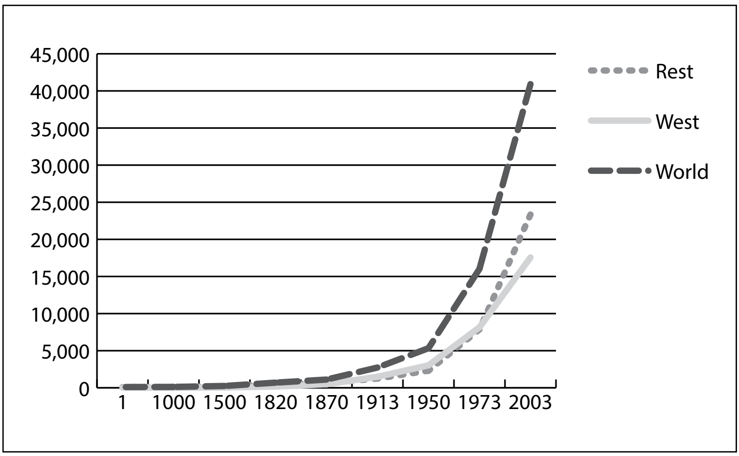

Figure 1: World Gross Domestic Product (billion 1990 international dollars), 1 AD to 2003. Source: Angus Maddison 2003.[1] *Chart by the author.*

1 Angus Maddison, *Contours of the World Economy, 1–2030 AD* (Oxford UP: Oxford, 2007), Table 2.1, p. 70.

The main story is obvious enough. After over fifteen hundred years of low income there is a steady increase from around 1750 onwards, with rapid increases after 1900. The world, has obviously become a great deal richer, with, in the case of the West, about half of that increase happening since 1970. Maddison, the author of this data, himself comments on the general picture as follows:

> Since 1820 the total product of the countries considered [...] has increased seventy-fold, population nearly five-fold, per capita product fourteen-fold and real per capita consumption almost tenfold. Annual working hours are down by half and life expectation has doubled.[2]

That's the basic phenomenon about which I will be talking, the enrichment of the world and the West in particular. This is a familiar subject, and at the same time poorly understood. As recently as 1994, the economic historian Donald McCloskey said: "It is in fact something of a scientific scandal that economists have not explained modern economic growth."[3] *Indeed*, and that is still true, but I hope to make it a little less of a puzzle by the end of the evening.

First of all I want to sow a seed of doubt in your minds about the economic facts underlying this impressive chart. Looking at it most of us would, I think, assume that something must have changed in the late 1700s to explain what one writer has called "take-off" in the early 1800s.[4] In other words, that an

2 http://www.ggdc.net/maddison/oriindex.htm

3 Donald McCloskey, "1780–1860: A Survey", in Roderick Floud and D. McCloskey, eds., *The Economic History of Britain, 1700–Present* 2nd Ed. (Cambridge UP: Cambridge 1994), 265.

4 W. W. Rostow, *The Process of Economic Growth* (W. W. Norton: New York, 1962), 103ff, and W. W. Rostow, *The Stages of Economic Growth* (Cambridge UP: Cambridge, 1971, 36ff.

increase in growth rate, or the productivity of the economy, is necessary to explain such a curve. I'm not going to assert that there was no increase in productivity, I think there was, but I don't want you to begin by assuming that it must be so to explain the curve. Look at this chart:

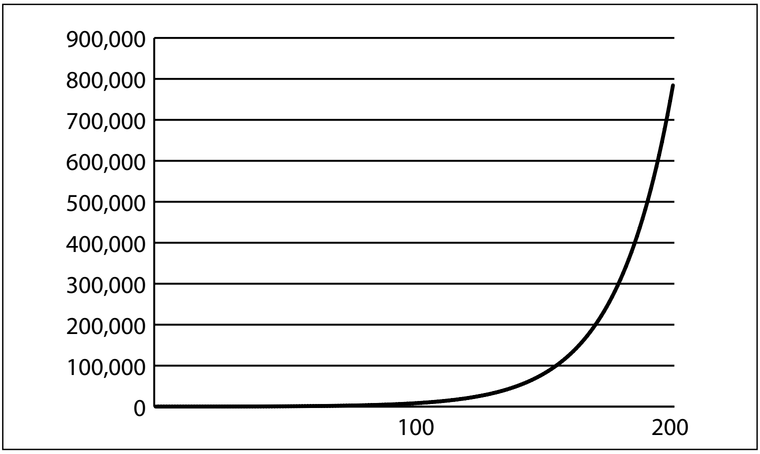

Figure 2: Arithmetically calculated 5% compound interest on an initial sum of 1 over 200 years.

I think you will agree that this is similar to the GDP chart. However, this isn't real world data. It's just the arithmetically calculated 5% compound interest on an original sum of £1 over 200 years. There is no hidden factor resulting in "take-off" at about year 100, no change in rate, no discontinuity, just 5% compound interest year after year. Yes, the magnitude of the annual interest yield increases, but the productivity, the rate, doesn't. My point is that these sorts of patterns, dramatic though they look, can result from completely stable generative conditions; there doesn't have to be a *revolution*, a major discontinuity at the foot of the curve, to explain them.

Having sowed that seed, I want to let it germinate while I talk about other things.

Our subject tonight is the theory of wealth, which has a name, plutology, a word not much used in English since William Hearn published his book with that title in 1864.[5] I have been thinking towards this subject for ten years, ever since I took a close interest in energy policy. Before that I was working on something else entirely, the philosophy of aesthetics, which turned out to be relevant in various ways.

My speciality was the language structures that make verse mathematically different from prose in English. This distinction allows me to say that even though, for example, R. D. Blackmore's novel *Lorna Doone* isn't printed as verse it has a mathematical microstructure that is closer to verse than to prose. I can even show that this pushes features such as word choice and grammar towards randomness.

That verse form research forced me well outside the conventional literary studies in which I had been trained. To solve my problems I had to work with a mathematical collaborator, one of Japan's best physicists as it happens, Hideaki Aoyama, who also writes on economics.[6] The excursion was a humiliating experience; academics in the humanities love to talk about interdisciplinary studies, but we hardly any of us actually undertake any in the proper sense of using the methods of other subjects to answer questions in our own field. Hideaki made me do this. I had to be precise about what we were counting, and why, and the answer to that last question required the use of a non-colloquial definition of order, complexity. I found his attitude quite difficult. Here was someone ruthlessly focused on framing problems so that they could be solved.

5 William Edward Hearn, *Plutology: Or the theory of efforts to satisfy human wants* (Macmillan: London, 1864).

6 Hideaki Aoyama, Yoshi Fujiwara, Yuichi Ikeda, Hiroshi Iyetomi, and Wataru Souma, *Econophysics and Companies: Statistical Life and Death in Complex Business Networks* (Cambridge UP: Cambridge, UK, 2011).

He had no patience with the endlessly discussable mysteries in which I had been immersed since my undergraduate years. If a research programme had not solved a problem, that was probably because the questions were badly framed.

This experience was fresh in my mind when I began to take an interest in energy policy, in which I could see that there was something seriously wrong, so wrong in fact that it was failing both as an energy policy and also as a climate policy. The proximal reason for failure was cost, and I set out to clarify those costs. Naively, I assumed that economists would have developed views about the importance of energy, which was intuitively obvious to me and almost every engineer I knew. However, I found that economists didn't think there was anything special about energy, and were generally relaxed about the impact of policy on energy costs, which, as I was often told, constituted only about 4% or 5% of a business consumer's annual expenditure. Nevertheless, I began to feel that there was an error here and that it was leading economics as a field to give poor advice to policy makers, advice with dangerous consequences. For example, subsidies to renewable electricity of about £4 billion a year at present, and entitlements that persisted for decades and took the cumulative cost into the hundreds of billions.

Now, I can in fact locate exactly when and why I began to entertain these doubts. When discussing costs with journalists one of the first things they would ask is *How much will it put on the average domestic electricity bill?* I found myself explaining repeatedly that about a third of a policy cost would hit households directly, because they consumed about a third of all electrical energy in the UK. The other two-thirds would in the first instance hit industrial, commercial and public sector consumers. At this point the journalist would think they had got enough, but I would be just getting into my stride. You have to remember, I would try to add, as they were putting the phone down, that it is ultimately households that meet all costs in an economy, so the other two-thirds of policy costs will hit the household *indirectly* in the costs of goods and services. Tesco must pay more to refrigerate milk, and will recover that cost at the checkout. Equally important, the direct impact on businesses would mean that the cost of living effect on households would be combined with a downward pressure on wages and rates of employment, which is not a good mix.

As a result, I began to toy with the idea that *all* costs were energy costs, at least when seen over long periods of time. In other words, that energy was somehow rendered in goods and services. Note, by the way, not "embedded" in those goods and services; you can't recover much if any of the energy used, so *embedded* is too strong a term. It's *rendered as*, it transforms or is transformed into something else, but what? Was it "value"? Was this an energy theory of value that I was looking at? Fortunately, my work in the philosophy of aesthetics kicked in here and reminded me that value was something in the perceiving mind, and that it was other qualities that inhered in external objects, and were valued. But there really has to be something about those objects that results in value; it's not at all arbitrary. Shakespeare's Troilus is quite wrong when he says, like any relativizing, knowledge-weary undergraduate: "What is aught, but as 'tis valued?", and the noble Hector is admirably outraged.

> But value dwells not in particular will;
> It holds his estimate and dignity,
> As well wherein 'tis precious, of itself
> As in the prizer: 'tis mad idolatry
> To make the service greater than the god [...] [7]

7 Shakespeare, *Troilus & Cressida*, Act II, Scene 2.

But what would this quality of valued objects be; and would it be possible to find a sufficiently abstract level of description at which all valued objects would have a common property, which would enable us to compare them, and how would this be related to energy?

When we talk about these valued objects we are talking about "wealth", in the archaic Anglo-Saxon meaning of something that augments human well-being, *wealth*. So, "Wealth" is a state of the world that increases wellbeing, in other words that satisfies or is likely to satisfy some human requirement (or "demand" to use the standard term in economics). These states of the world vary in character to an extraordinary degree, from a glass of cool water in the desert, to a mug of hot tea on a cold night in Northumberland, from a roof over your head, to the floor beneath your feet; from the engine that makes your car move, to the brakes that stop it; from the sandwich on the shelf in the supermarket when you want it; to the sewerage that carries the digested remains safely away when you have finished with it.

I will further claim that mental states, ideas of all kinds, elaborate conventions such as languages, or intellectual traditions, scientific conventions, texts, computer data in electronic storage, even societal institutions, are *wealth* or potential wealth in this broad sense.

Can these diverse states really have any useful abstract property in common? Yes, they are all of them, without exception, improbable. They are all of them, without exception, physical states far from thermodynamic equilibrium, and the world was brought, sometimes over long periods of time, into these convenient configurations by energy conversion, the use of which reduced entropy in one corner of the universe, ours, and increased it by an even larger margin somewhere else.

The more ordered and improbable our world becomes, the richer we become, and, as a consequence, the more disordered the universe becomes overall.

In a sense this is, or should be, rather obvious, but thermodynamics is not popular in economics. Forty years ago, the eminent North American economist, Paul Samuelson mocked those seeking to link the two:

> There really is nothing more pathetic than to have an economist or a retired engineer try to force analogies between the concepts of physics and economics. How many dreary papers have I had to referee in which the author is looking for something that corresponds to entropy or to one or another form of energy?[8]

Analogies may indeed be misleading, but it would be nothing short of bizarre of Samuelson to suggest that the theory of entropy does not in some way apply *literally* in economics. It is, after all, the same world under consideration in both physics and economics, and it is obviously desirable to have as much consistency as possible between the propositions in all the fields of human knowledge. The view I'm recommending here is that of the great Harvard philosopher Willard Quine, in which he suggested that human science is a network of propositions extending from history on the one side to mathematics on the other.[9] These propositions have been formed by repeated experiment to render them an accurate reflection of the sense data. As a matter of fact they are not all mutually consistent, and experience teaches us that this is an indication of the potential for improvement.

8 Paul Samuelson, "Maximum Principles in Analytical Economics", *American Economic Review* 62 (1972), 249–62.

9 See for example, W. V. O. Quine, *From Stimulus to Science* (Harvard UP: Cambridge, 1995).

How could economics improve its consistency with the natural sciences? A first step would be to take physicalism seriously in the grounding or ontological sense. In other words, economists should ask: *What are the physical states about which we are talking?* Consider the factors of production in economics: Land, Labour, and Capital. These are the grounding ontological postulates of the field, but they are only vaguely defined in themselves, and so can only be loosely consistent with physics, and their analytical power suffers as a consequence, in much the same way that the categories of primitive chemistry, Earth, Air, Fire and Water are poorly defined as elements, and so only loosely consistent with our observations, particularly those of modern physics, and as a result lack power. The point is not that Earth, Air, Fire, Water, Land, Labour, and Capital, are downright wrong, obviously not, but rather that we can do better. You could do chemistry today with Earth, Air, Fire, Water, if you chose, but it would be feeble stuff, lacking in both descriptive and predictive power. I suggest that the same is true of Land, Labour and Capital in economics.

Now, you might at this point say that there are such things as "emergent properties", in other words that the macro physical level studied by economics is more than the sum of its physical parts, as studied by physics, and that the economist's propositions are tailored to that higher level of analysis. Very well, but let's not get this fact out of proportion. An emergent property is not a transcendent one. In popular science the distinction is frequently blurred, with a lot of loose talk that creates in readers a specious feeling of freedom, a lack of constraint on possibility. It's the trigger of the literary writer's second biggest gun, the largest being death.

So emergent properties, such as those in economics, do not transcend the physical constituents studied by physicists, indeed they are fully determined by them. A classic example of this kind of relationship is water. At temperatures above zero degrees centigrade and at sea level water is a fluid, while hydrogen and oxygen, its constituent elements, are both gases. If you merely mix hydrogen and oxygen, in other words if you simply add their properties, the resulting mixture is still a gas. If you *combine* hydrogen and oxygen, water results, with the emergent properties of fluidity, wetness, potability, and so on. There is nothing transcendent about that. The emergent properties of water are fully determined by the different properties of hydrogen and oxygen, which is why when combined they reliably produce water with the emergent properties that we know, rather than, from time to time, some other substance with different emergent properties.

Exactly the same will be true of economics. Yes, human beings and their activities show a wide range of emergent properties; but there is nothing transcendent, or undetermined about those properties. They are fully determined, as far as anything is determined in the weird world revealed by quantum physics.

All that this amounts to, really, is, as I said, taking our physicalism seriously; in other words the view, not always comfortable, that the physical substance of the world determines all the facts that we perceive, indeed that it constitutes them.

This bears heavily on the main point raised by Samuelson. You will recall he complained about engineers and others "forcing analogies". I have some sympathy with that. Analogies in the sense Samuelson meant are not always helpful. He was referring to casual or explanatory analogies, which are convenient but disposable rhetorical devices. For example, a lecture is like an apple; the bits towards the middle can be quite hard to chew. Little remains afterwards from such an analogical usage. The user's commitment to the comparison is weak. Indeed, when we use the term *analogy* as Samuelson did we are making a claim not about the relationship between two objects, but about our commitment to the assertion of that relationship. By contrast when we assert that the relationship is not analogous, but rather that it is *literal* we are again not making an assertion about the relation between the objects, but rather to the degree that we take that relationship seriously and are prepared to defend, to expand, and to use it.

In any field of human knowledge, the groupings and categorisations that we derive are, in a technical sense, *analogies*, comparisons and assertions of similarity, and these are comparisons and assertions that can be explained in depth. In other words, when a science makes *ontological* claims about things, it is defining objects and grouping them together according to similarities between their properties, and examining the causal relationships between these objects.

What I am proposing here is an analogy in this much stronger sense. I'm not taking one of the emergent properties of the economy, wealth, and suggesting a weak, Samuelson-type, analogy, a passing similarity, with the concept of entropy in physics. I'm using it in a *literal* sense implying that the similarities detected are numerous, strong, causally relevant and give power. It was Coleridge, you may recall, who said that the only true knowledge is that which returns as power.

Such progress in any subject that you care to name all but invariably goes along with refinements in ontology, refinements in statements about the sorts of things that are under consideration. I have already mentioned Earth, Air, Fire, and Water, the ontological constituents of early chemistry and physics, now replaced with a great scheme of fundamental particles, and the atoms of elements, and complex molecules. The consequences of refinements in ontological claims can be quite dramatic, and unexpected. One of the greatest advances in the life sciences came about from the description of the emergent properties of a complex molecule, DNA.

In this context, and looked at with a cold eye, it is mistaken of Samuelson to put the burden of proof on those who think thermodynamics, for example, *relevant* to economics. The burden of proof is on those who think the physical sciences are *irrelevant* to any subject whatsoever.

Why does this matter so much? Because if you regard economic activities as physical activities with the focus that I have suggested, then you see them as engines, systems that use energy to do work, and if they are engines, then energy is not just another input, and, furthermore, the results of that work must be considered in the same general framework as all other physical objects , namely thermodynamics.

Now at this point you might wonder why economics has been so slow to seize this potential benefit. It is, after all, notorious that the insight delivered by economic knowledge is limited, a point that was famously brought into sharp focus by Her Majesty the Queen's question to the London School of Economics in 2008, about the crash: "Why didn't you see this coming?" The profession didn't have a good answer, because it didn't want to admit weakness. But economists could have said, and it would have been a good defence, that the field of economics is so new that it is still finding its feet, unlike physics which is mature and up and running. As the great economist Leontieff pointed out in the 1950s, the nineteenth century physicist James Clerk Maxwell would struggle to understand twentieth-century physics, but his contemporary, the economist John Stuart Mill would fit in with twentieth-century economics without any difficulty:

> Physics, applying the method of inductive reasoning from quantitatively observed events, has moved to entirely new premises. The science of economics, in contrast, remains largely a deductive system resting upon a static set of premises, most of which were familiar to Mill and some of which date back to Adam Smith's *Wealth of Nations* [in 1776].[10]

That is still true, and given the number of gifted people who have worked on the field it is interesting to ask why it has changed so little. The answer, perhaps a surprising one, is that economics became mathematical early in its development, in the later part of the nineteenth century, in the writings of Walras, Jevons, and, pre-eminently Alfred Marshall, and of course in the twentieth century it has become rigorously mathematical. This was possible because economists could draw on the large bodies of numerical data, commercial and monetary and pricing data, spontaneously generated by the economic process itself. This is, I believe, a unique phenomenon in the sciences. No other subject leaves a numerical trace in this way. Consequently, the field of economics was able to become mathematical before its ontology had been rigorously clarified by philosophical reasoning. Economists didn't have to work out what to count, because the material was counting things for itself. Contrast this with physics, for example. The natural phenomena under consideration do not generate their own numerical data. Ontological precision had to be reached before it was possible for physicists to count objects and then develop a mathematical representation and analysis of the subject. The difference with economics could not be more striking. In physics, quantification and mathematics have fed back into the philosophy of the field, constantly revising its

10 Wassily Leontieff, "Input-output Economics" (1951), in *Input-Output Economics*, 2nd Edition (Oxford University Press: New York, Oxford, 1986), 3.

ontology. In economics, the ontology has never been required to change, because numerical data is generated in the absence of any such theory. Economists have therefore concluded that they don't need an ontological theory beyond that assumed implicitly and spontaneously by men and women in economic action. I believe that is a mistake.

I mentioned my physicist friend Hideaki Aoyama earlier. I asked him once about his interest in economics, and how he got on with economists. He doesn't talk a lot, preferring numbers, so his replies are always carefully phrased. "Economists…" he said, "well, they just don't know what they're talking about." That wasn't colloquially dismissive. He meant exactly what he said: the references of an economist's propositions are insufficiently precise to be usefully consistent with the physical world as it is described in the natural sciences. They don't know *what* they're talking about. Look into any economic study on growth, even the best, and you will find a truly remarkable lack of clarity about the substantial reality of the topics under discussion, even and especially in regard to key terms such as *growth*, and *capital*, and *value added*. All these matters are defined by economists in terms of data that is spontaneously generated by economic actants themselves. Judging by the results, that is not satisfactory.

All this is easy enough to say, but hard to fix. Look how long it took physics and chemistry to really get moving, look how long it took for the impacts of that progress to hit biology. It takes time – and energy, by the way. And economics has, of course, made some progress, but in certain crucial areas, and energy is perhaps the most important of these, the lack of sophistication leads to bad advice.

Here is a remark from the International Energy Agency, an agency of the OECD states:

> Structural shifts in the [Chinese] economy, favouring expansion of the services sector rather than heavy industry (both steel and cement production are likely to have peaked in 2014), mean that 85% less energy is required to generate each unit of future economic growth than was the case in the past 25 years.[11]

Clearly we are expected to take comfort from this remark, and to conclude that because China will have built many complex structures of steel and cement it will now be able to "grow" in a way that is no longer as reliant on energy. But, on reflection, this only means that the service sector is indirectly dependent on the energy consumed and rendered as complex structure during an earlier phase of growth. In other words those complex structures are later energised to generate more complexity. But thermodynamics reminds us that this energy intensive structure needs maintenance and that none will last forever. In other words, standard economics offers false comfort about such economic transitions. We never escape from the need for energy. Whatever the short-term variations might look like, the trend over time is for greater energy use, to deliver and crucially to maintain and replace a human sphere that is progressively further away from thermodynamic equilibrium. There is no point at which you sit down and have a rest.

Now you might think that the IEA is a one-off, so here is another example. Chatham House, The Royal Institute of International Affairs in London, is currently advertising for someone to direct a new Centre to "accelerate the decoupling of resource use from economic growth". Consider what that means. The economic engine is going to get bigger, it won't

11 IEA, *World Energy Outlook* (2015), Executive Summary, p. 2.

need repairs, it will last forever, and it won't need any fuel. This is perpetual motion under another name.

So energy conversions are a crucial part of economic theory, but in order to tell the story of energy, the study must be complemented with an examination of the results of those energy conversions, which are complex, low entropy, material states, many of which are, as I have already noted, then energized to create further order. Any good economics will capture these relationships, particularly over time, for that is how we are going be able to explain change in the human sphere, and shed light, in particular, on the chart with which I began. In that growth story the Northumbrian coal fields have an important part, and if there is anyone here not, at this point, thinking about the "Industrial Revolution" I would be surprised. However, it is a term as deeply misleading as it is ubiquitous. Indeed, it is an obstacle to understanding, and I must undermine it before I can proceed to give a sketch of global thermo-economic history.

You will recall that I quoted McCloskey as saying that economics couldn't explain modern growth. There are a number of factors in that failure, and one is certainly, in my view, the weak ontology of economics. Another reason, is the mistaken belief in a discontinuity, *The English (or British) Industrial Revolution*, the explanation of which will account for the subsequent explosion of growth. The literature on this subject is vast, highly intelligent and, surprisingly, inconclusive. It has many of the hallmarks of an endlessly discussable mystery resulting from a misframed question.

In the interest of brevity I will summarise the main defects of the term, which are widely acknowledged: Firstly, the economic changes under consideration were not solely British. There were significant changes all over Europe before and during the eighteenth century, particularly in the Netherlands, but also in France. Secondly, those changes were not solely industrial. They were also agricultural, artistic, horticultural, linguistic, mathematical, medical, musical, zoological, and many other things besides. Thirdly, only in the weakest of senses are the events in Britain 1750 to 1820 a "revolution". It was a phase, and not a particularly intense phase, in a process that began centuries before and is still continuing. To call such a thing a revolution is, as one eminent historian has said, "making very free with words".[12]

But you might think that it is a matter of common sense; people at the time knew that there were industrial changes so large that they were revolutionary. However, that is not the case. By the 1830s, yes, people were noticing that life was changing, and that Britain was much richer than it had been before, though in fact, as is well recognised by historians, "much of the England of 1850 was not very different from that of 1750".[13]

It should come as no shock then that no one in Britain 1750 to 1820 referred to an *English or British Industrial Revolution*. That term did not enter common currency in English until the 1880s. Furthermore, the phrase, like the word *industrial* itself, is French in origin, *revolution industrielle*, and was not in the first instance used to refer to England. French writers in the 1790s employed it to express the wish that the political revolution they had just experienced should be extended to other

12 G. N. Clark, "The Idea of the Industrial Revolution", David Murray Foundation lecture in the University of Glasgow, 15 October 1952 (Jackson, Son, & Co: Glasgow, 1953), 29.

13 A. E. Musson, *The Growth of British Industry* (Batsford: no place, 1978), 149.

departments of life, manufacturing for example. It is more aspirational wit than anything.[14]

This usage became commonplace in early nineteenth-century France, but, again, initially with no reference to England. But that comparison gradually asserted itself. In 1828, J. B. Say, Professor of Economics at the College de France, referred to the economically "revolutionary" effects of cotton spinning machines in England and elsewhere,[15] and in 1837 Say's pupil and professorial successor, Jérôme-Adolphe Blanqui, noted what many Frenchmen must by then have been thinking, namely that it was quite remarkable that politically unrevolutionary Britain, of all places, was modernizing its economy. He wrote:

> While the French Revolution was making its great social experiments over a volcano, England was beginning hers on the solid ground of the industries. [...] The conditions of labor underwent the greatest modification they have experienced since the origin of society. Two machines, henceforth immortal, the steam-engine and the spinning-machine, overturned the old commercial system and gave birth almost simultaneously to material products and social questions unknown to our fathers. [...] That transformation from patriarchal labor into industrial feudalism, in which the workman, the new serf of the workshop, seems bound to the glebe of wages, did not alarm the English producers, although it had a character of *suddenness* quite adapted to disturb their habits. [...] However, hardly was the industrial revolution born from the brain of those two

14 Anna Bezanson, "The Early Use of the Term Industrial Revolution", *Quarterly Journal of Economics* 36/2 (Feb. 1922), 343–349.

15 Anna Bezanson, "The Early Use of the Term Industrial Revolution", *Quarterly Journal of Economics* 36/2 (Feb. 1922), 348.

> men of genius, Watt and Arkwright, when it took possession of England.[16]

He thought it was rapid, industrial, concentrated within one state or population, and, a crucial point, that it was the source of great changes that elevated one part of that population and depressed another. In other words, that it had all the features that would justify the use of the term "revolution". He was not making a weak analogical comparison with a political revolution. He was saying that it literally was a revolution, an industrial one.

Blanqui was not obscure. He was distinguished on family grounds alone; his brother was the notorious political agitator, Louis Auguste Blanqui (1805–1881), and Jerome-Adolphe was himself a prominent and credible economist, and the book in which this passage appeared, *Histoire de L'Économie Politique en Europe*, was the first of its kind. It would have been required reading for anyone interested in the field.

One such reader was very probably Friedrich Engels, who found exactly what he wanted in the idea of the English Industrial Revolution, a term that he translated precisely into German, first in essays in 1844, and then in his *Condition of the Working Class in England* (1845). Here was a bourgeois revolution, creating an oppressed, politicised, and consequently revolutionary working class. Probably as a result, Marx then adopted the term and the concept, and both were incorporated into Volume One of *Das Kapital* (1867). The idea of an English industrial revolution was now current within radical

16 Jérôme-Adolphe Blanqui, trans. Emily J. Leonard, *History of Political Economy in Europe* (G. P. Putnam's: New York and London, 1885), 430–431. Originally published as *Histoire de L'Économie Politique en Europe* (Paris, 1837).

socialist European circles, and came with the imprimatur of two of its major figures.

But it still wasn't used in England, and this silence is remarkable, not because we would expect English writers to pay much attention to Blanqui or Engels, or Marx, even if they knew of them, but because these were the people confronting the phenomenon directly. Why did they not spontaneously generate this term, or something similar?

Consider the facts of the chronology. The field of modern economics was founded in the English language by Adam Smith, T. R. Malthus, and David Ricardo during exactly this period, 1750 to 1820. Not one of them uses the term Industrial Revolution or anything like it. Robert Owen, the idealist social thinker and factory owner, wrote extensively about the changes in the manufacturing system but never used the term. Neither Robert Southey nor Thomas Macaulay, who disputed Southey's *Colloquies* of 1824 in his own devastating essay of 1830, use the term. Carlyle came close, in *Sartor Resartus* (1834, but written in 1830/31), when he spoke of steam engines "rapidly enough overturning the whole old system of Society" in favour of "Industrialism", and while Engels knew of this usage, he would not have found the exact words there. Given Carlyle's knowledge of the French Revolution that is surely significant. John Stuart Mill, who almost certainly read Blanqui, did use the term once in his *Principles of Political Economy* of 1848, but he wasn't referring to England and he didn't use capitals. Neither Dickens's *Hard Times* (1854), nor Matthew Arnold's *Culture and Anarchy* (1869) use the term. Mrs Gaskell doesn't use it; Disraeli doesn't use it, although he employs the term "revolution" often and with broad application. It doesn't even appear in mid-century standard textbooks like Fawcett's *Manual of Political Economy* (1863). Perhaps most striking of all, W. S. Jevons, one of the greatest mid-century economists, wrote an entire book on *The Coal Question*, published in 1865, arguing vigorously that coal lay at the root of modern British wealth, and used the term "industrial revolution" only once, and though in reference to England it is not capitalised. Jevons' use, the first in English of which I am aware, appears to have been drawn from the French writer, Natalis Briavoinne, whose *De l'industrie Belgique* of 1839 makes frequent use of the term, and may either derive directly from Blanqui or perhaps reflect what was becoming a general French usage. Doubtless this does show that the phrase was beginning to leak into English, but Jevons' handling of the term is half-hearted, and does not, as far as I know, appear elsewhere in his writings.

While, I cannot claim to have made an exhaustive survey of what is after all a large body of writing, or rule out the discovery of other instances, it should be plain from these examples that the statistical signal coming up from the literature is very weak at best, and that where you might most expect to find the term used precisely, prominently and repeatedly if it had a spontaneous life in English, it is conspicuously and all but completely absent.

How then did it become current in English usage? Engels and Marx were known, the latter in a French version, but it was almost certainly the publication in 1880 by two American writers of a translation of Blanqui's *Histoire* that brought it to the attention of a young tutor in political economy at Balliol College, Oxford, Arnold Toynbee. He took the Blanqui interpretation, and probably that of Marx, whose work he had definitely read, adding his own views, which were those of a liberal Christian reformist, and he presented them in university lectures for the History Schools in 1881 and 1882, and also to large audiences of working men and employers in Bradford, Bolton, Leicester, London, and Newcastle in 1880 to 1882.[17] Indeed, he was here in Newcastle in early 1881 talking on "Industry and Democracy", and he refers explicitly to what he calls the "revolutions" in industry of the late eighteenth and early nineteenth centuries.

Toynbee died unexpectedly in 1883, and his writings and speeches were edited by his wife, herself a distinguished figure in liberal reform circles, under the title *Lectures on the English Industrial Revolution*, the first of many similar titles.[18] It would be a mistake to think this a slight contribution; Toynbee's influence was vast, and it is with us today. Part of this was personal. He had by all accounts great presence as a speaker, and he used this to transmit a passionate commitment to the view that the English working people were the victims of an un-Christian middle class economic coup that had displaced the church-led charity of the medieval period. Unlike Marx and Engels he had no Hegelian dialectical theory of history, and he did not want a counter-revolution; he aimed through political, moral, and state-led social reform to institute a compassionate Christian society. This made his interpretation of the term "Industrial Revolution" more influential in England than it would have been in the hands of a revolutionary. More influential than Marx and Engels, for example, more influential than Blanqui, whose name, thanks to his brother, was synonymous throughout Europe with attempts to achieve political change through conspiracy and violence: Toynbee by contrast was Oxonian, British, Christian, and respectable.

17 "Arnold Toynbee", *Oxford Dictionary of National Biography* (2004), Vol. 55, p. 177.

18 Arnold Toynbee, *Lectures on the Industrial Revolution in England* (Rivingtons: London, 1884).

He also had influential and gifted friends and pupils. Benjamin Jowett, Master of Balliol, wrote an introduction to the *Lectures*. Alfred Milner, later Viscount Milner (1854–1925), the distinguished public servant and politician, a close friend, wrote a memoir of Toynbee, and revised the lectures for publication. The student from whose notes Toynbee's lectures were reconstructed became eminent as Sir William Ashley (1860–1927), the first professor of economic history at Harvard.

So this French concept, first articulated in detailed reference to England by Blanqui, was carried into more than academic English usage through Toynbee and with all the conceivable advantages, and soon it was standard. It was in the *Encyclopedia Britannica* by 1887, and Sidney Webb used it in his contribution to *Fabian Essays* (1889). After that time the term becomes so common in the literature that citation is redundant. The economic changes to which Toynbee was referring may in fact have been slow, but the idea of an "Industrial Revolution" spread like wildfire, and today it is received wisdom in spite of continuing dissatisfaction amongst specialists.

What this extraordinary chapter in the history of ideas teaches us is that the concept of an "English Industrial Revolution" has had a life that is independent of its accuracy as a description of the economic and social facts. Use of the term has been further complicated and secured because alongside the negative appraisal, implied in Toynbee's handling, and in part because of it, the concept was used to support a not ungrounded pride in Britain's industrial leadership, a pride permeated with nostalgia because it was already evident in the later years of Victoria's reign that this leadership was a thing of the past. Indeed, the antiquarian and sentimental elements of the modern heritage industry were becoming evident as early as 1877 when staff at the Patent Office Museum noted with dismay that visitors to Stephenson's *Rocket* were gradually destroying the engine by "picking off scaling pieces of rust [...] as memorials".[19]

So much for the Industrial Revolution. Once you have disposed of the mistaken view that there is a discontinuity in this story, somewhere in late eighteenth or nineteenth centuries then we can begin again, and try to explain that which is actually observed, and the account that I give is the progressive reduction of entropy in, the increasing complexity of, the human sphere. That change can be roughly tracked by standard economic measures such as GDP, which we can use as a proxy for entropy measurements, which are quite beyond us at present.

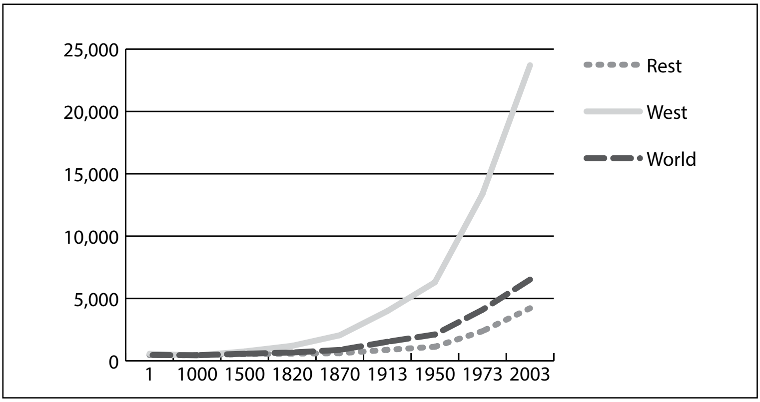

Figure 3: World Gross Domestic Product per capita, 1 AD to 2003 (1990 international dollars). Source: Angus Maddison 2003.[20] *Chart by the author.*

Let's look again at a chart of World GDP, and home in on the same data divided by population. Clearly individuals, like the economies in which they live have got richer over this time period, with the West, accounting for most of that average

19 Quoted in Ben Russell, *James Watt: Making the World Anew* (Reaktion Books: London, 2014), 228.

20 Angus Maddison, *Contours of the World Economy, 1–2030 AD* (Oxford UP: Oxford, 2007), Table 2.1, p. 70.

enrichment, and becoming spectacularly rich by historical standards in the last two or three hundred years, with a large part of that enrichment in the last few decades.

Concentrating on the first part of that chart still other things become clearer. Below is the data for GDP per capita from 1 to 1913 AD.

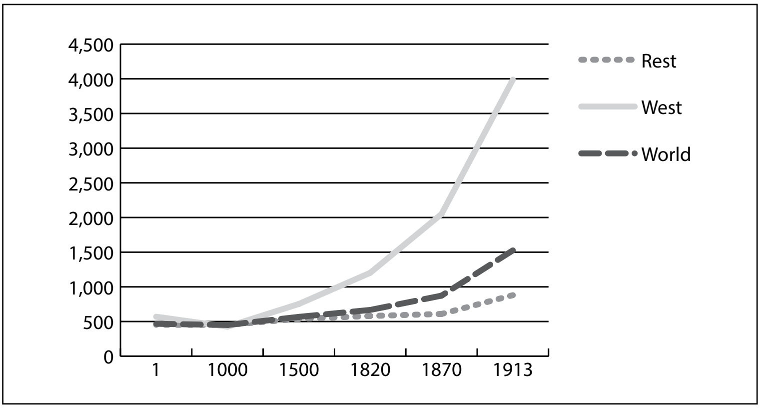

Figure 4: World Gross Domestic Product per capita (1990 international dollars), 1 AD to 1913. Source: Angus Maddison 2003.[21] *Chart by the author.*

Note that at the height of the Roman Empire, the West was considerably richer than the rest of the world. The decline of Rome was economically significant – it haunts European culture for a reason – with the West only recovering its per capita lead at some point in the period 1000 to 1500, and then pulling steadily away.

The fundamental story here is, as I say, about changes in entropy, degrees of order and improbability. Consider that complexity in more detail and it is clear that while a large

21 Angus Maddison, *Contours of the World Economy, 1–2030 AD* (Oxford UP: Oxford, 2007), Table 2.1, p. 70.

part of it is the result of natural selection on organic forms – the bodies that bootstrapped the process and continue to contribute – the vast majority of it is now the result of what we can call economic and cultural activity. In essence this is a Lucretian view, with all the phenomena in the universe being the development of material structures as a consequence of the initial starting conditions, in other words that the world around us is the emerging property of the universe.

You will find broad-brush accounts of this in the writings of the Harvard cosmologist Eric Chaisson:

> Nature's many varied complex systems – including galaxies, stars, planets, life, and society– are islands of order within the increasingly disordered Universe. [...] A wealth of observational data supports the hypothesis that increasingly complex systems evolve unceasingly, uncaringly, and unpredictably from big bang to humankind. This is global history greatly extended, big history with a scientific basis, and natural history broadly portrayed across ~14 billion years of time.[22]

By contrast, I'm offering something relatively microscopic in focus, a view of one small part of the evolution of everything, to use Matt Ridley's phrase,[23] the development of the current state of the human sphere.

But this perspective immediately begins to yield dividends in our history of human complexity. Those claiming a

22 Eric J. Chaisson, "The Natural Science Underlying Big History", *The Scientific World Journal* (2014), 1. Article ID 384912, http://dx.doi.org/10.1155/2014/384912. See also Eric J. Chaisson, *Cosmic Evolution: The Rise of Complexity in Nature* (Harvard UP: Cambridge Mass., 2001).

23 Matt Ridley, *The Evolution of Everything* (Fourth Estate: London, 2015).

discontinuity in eighteenth-century England have had to take the view that the economy flatlined before the discontinuity, and that the discontinuity enabled take-off.[24] But when we look at the data we find very gradual growth over the entire historical period.[25] The problem then is to explain both facts, the long period of slow growth, and the striking upturn, but without presuming a discontinuity for which we can find no evidence.

You will recall that when we started I said that curves of this kind are not unusual, and I showed you a compound interest curve, and argued that the real world data could in principle be explained by the compounding of a steady growth rate. Of course, in the real world data, there could actually be a change of rate and in fact, cliometricians all report such a change, of varying degrees. But as the compounding curve shows, these rate changes are in fact unnecessary to that growth.

However, as one economic historian, David Landes – a believer in the discontinuity – has quite properly pointed out, growth rates must have been much lower in the past, because if we decompose wealth from the 1820s, say, using even the modest growth rate in that year, "impossibly low levels of income" are quickly reached.[26] That is correct; growth rates in the past must have been extremely low. But, emphatically, it does not, as Landes thinks that it does, show that a change in the rate of growth constitutes "a discontinuity, a break in the curve", and explains the subsequent dramatic growth. As

24 Gregory Clark, *Farewell to Alms* (Princeton UP: Princeton, 2007).

25 N. F. R. Crafts, *British Economic Growth during the Industrial Revolution* (Clarendon Press: Oxford, 1985).

26 David S. Landes, "The Fable of the Dead Horse: or, The Industrial Revolution Revisited", in Joel Mokyr, ed., *The British Industrial Revolution: An Economic Perspective* (Westview Press: Boulder, 1993), 156.

we have seen, it is not necessary to have a rate change at all; compounding is sufficient.

Nonetheless, Landes' observation is suggestive. The rate change in the eighteenth century implies that extremely low and probably inconsistently positive levels of growth are necessary to explain the very low average and only fractionally increasing levels of riches over historical time.

In other words, we have been misled by the superficial appearance of the data curve into thinking that we need some special explanation for the upturn in riches. On the contrary, that part of the story is easy to explain. Compounding, even with a low growth rate, is perfectly adequate.

The part of the story that we do not understand is the long period of low wealth. That is to say, we should not be asking **"How did the world get rich so quickly?",** but, **"Why were we poor for so long?"** *Why didn't the arithmetical consequences of wealth compounding rapidly lift human beings out of poverty long before the 17th to 21st centuries?*

My answer to this is that the nature of the energy supply for the majority of human history (and prehistory come to that) was not adequate to generate and preserve adequate material complexity, capital of all kinds, to stabilise compound growth, and that it took several thousand years to gradually and only falteringly accumulate just enough complexity, and thus secure, over quite long periods of time, a transition, from organic sources of energy to the fossil fuels, a transition that could firmly sustain further compound growth, and even a rate change.

For most of human history the world's economies were overwhelmingly dependent on flows of organic energy, mostly derived from the sun.[27] These flows are thin, low-density – relatively high entropy, in fact – and extremely variable both seasonally, and from year to year. The principal limitation of these resources, then as now, is that their collection and delivery requires the commitment of a quantity of energy not much smaller than that yielded. In other words, to use the jargon of this field, the margin of Energy Return on Energy Invested is small. The existing complexity, of all kinds, buildings, improved land, and intellectual and institutional systems, and the people that give them real body, had to be maintained from this margin, so it is not surprising that the rate at which further complexity was added to the store of societal wealth was low.

Organic sources of energy were still dominant in Europe in the early nineteenth century, and overwhelmingly so in the early eighteenth century, though in certain parts of Europe there were signs of a gradual transition. The Netherlands of the seventeenth century was an extremely advanced economy, largely grounded in, first, improved sailing technology, and then the use of peat, a relatively dense stock of energy. The relation between the Netherlands and England was so close intellectually, commercially, and politically, and not just because of the events of 1688, that we can speak here of the confluence of two sophisticated European societies, one very sophisticated indeed. In both these economies compounding had been stabilising for some time, with the combined result that in the early and mid-eighteenth century, British individuals, society and economy accumulated sufficient complexity to enable the better employment of existing resources already in use, including crucially the energy stored in coal, a fuel that in the British isles was close to the surface of the land, and to the

27 See E. A. Wrigley, *Energy and the English Industrial Revolution* (Cambridge: Cambridge University Press, 2010).

sea, making extraction and delivery relatively easy, and giving a high energy return.

In a conventional account it is at this point that the speaker says that the impact on the British economy was dramatic and transformational. However, while the impact of coal was real, the effects manifested themselves only gradually, exactly as you would expect from the theoretical context that I have outlined. Economies are in a constant process of maintaining and repairing existing low entropy material states and only then being able to extend those holdings. The gradual introduction of coal could not effect a rapid change in that circumstance.

So, I have argued that economic change is the *evolution of entropy*. A physicist would add that it couldn't very well be anything else. This evolution is not a purely English occurrence, but a process of worldwide and slow accumulation of complex material states of all kinds, hand-held tools, to acqueducts, to ideas about the circulation of the blood, material states that by various routes enabled compounding to stabilise, and so directly and indirectly enabled a progressive energy transition away from the low-density flows of the organic economy.

What happened in England was not a phenomenon complete in itself, a revolution, which was then exported to the rest of the world as a product. As early as the first decades of the nineteenth century the entropy evolution including the energy transition, still in progress in England, was no longer a solely English phenomenon, if indeed it ever was. Individual companies all over the world were beginning to benefit from the wealth of the English companies with whom they traded, particularly those in the United States, which rapidly adopted the cotton technologies,[28] improving on what they took,[29] and whose industry was so mechanised that in the manufacturing sector "U.S. labor productivity was already substantially higher than that in Britain by the early nineteenth century".[30]

Importantly, a large part of the growth observed in the American economy, over the first half or so of the nineteenth century, when it equalled and then surpassed the United Kingdom in aggregate GDP was the result of the bootstrapping by British coal of the use of American wood, the extraction and use of which could not have taken place without the advances in complexity, highly efficient steam engines, that had occurred previously in England. The improbable outputs of the increasingly coal-based economy in England made improvements possible in the old energy providers, in waterwheels, in windmills, in sailing ships, and, in the United States, in the use of wood as a fuel.

To emphasise, there is no revolution here, with one dispensation being swept away and replaced by another. This is an *evolution* of entropy, involving an energy transition but not limited to it. It started before the period we are considering, and it is still continuing, and sometimes its movements are not in the directions we might naively expect. Coal was not used in large volumes in the United States until after 1850, and did not surpass wood as the major fuel source for the US until about 1885.[31] In fact in the century from 1805 to 1905

28 Robert C. Allen, *The British Industrial Revolution in Global Perspective* (Cambridge UP: Cambridge, 2009), 211–212.

29 David Landes, *The Wealth and Poverty of Nations* (Little, Brown: London, 1998), 299.

30 S. N. Broadberry, "Comparative Productivity in British and American Manufacturing during the Nineteenth Century", *Explorations in Economic History* 31/4 (Oct. 1994), 521–548.

31 United States Energy Information Administration (EIA), *Annual Energy Review* (2009), Table E1, page 385.

wood accounted for about half of all the energy consumed in the United States.[32] The great riches of late nineteenth-century America – the wealth of Henry James' heiresses – was as much wood as it was coal. In Britain over the same period wood accounted for less than half of one per cent of all energy consumed.[33]

But reflect a little. Isn't it striking that as early as 1850 the United Kingdom, a long-established European state, and the United States, a recent one, were economically not that different in magnitude? By 1900 US GDP was close to double that of the UK. And of course, the European economies were not far behind, and they never had been. Compounding had been stabilising in those countries for centuries. Maddison's data suggests that both the French and German economies almost doubled in size between 1820 and 1860. Within a few decades all these economies were so sophisticated that they were returning complex states of matter to England for capital investment. For example, the installation of electric tramways throughout Europe in the late 1880s, including England, was fundamentally a technology transfer from the United States. Electrification of the London tube network in the early 1900s was not only financed by Americans but built almost entirely with electrical equipment, from generators to motors, designed and made in Schenectady and Pittsburgh.[34]

The most we can say is that the entropy evolution was briefly focused in these islands, and that within a short time complex

32 Calculated from: https://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb1601

33 Calculated from Paul Warde, "Energy Consumption in England and Wales 1560–2000", at http://www.histecon.magd.cam.ac.uk/history-sust/energyconsumption/.

34 See Byatt, I. C. R. *The British Electrical Industry 1875–1914: The Economic returns to a new technology* (Clarendon Press: Oxford: 1979).

material states, machines, yes, but also ideas, organisational methods, institutional structures, texts, and improved materials, were flowing in all directions, backwards and forwards throughout the world, with quite astonishing results wherever they found fertile ground and could could further stabilize compounding. Think of Japan.

There are obvious questions arising from this account, and I'm sure that you are already thinking of them. You might be saying, if energy is this important to wealth creation and maintenance, then an energy shortage is really no laughing matter. Are we running out of energy? And then there is climate change, which arguably makes the use of remaining fossil fuel extremely unwise.

But are we actually running out of dense, high-grade energy sources? No. There are large quantities of fossil fuels remaining; there are extremely large sub-atomic resources; contemporary nuclear fission has only scratched the surface. So, as far as mere quantity goes, there is no danger of running through these resources in the imaginable future. But there is a proviso, and it is obvious from the history that we reviewed. In order to make use of an energy resource it is necessary to have sufficiently complicated states of matter to realise the systematic economy that can convert and deliver that energy for human purposes. The simple discovery of an energy source is not enough.

Let me give you an example. In about 330 BC Alexander the Great and his victorious armies entered the Caspian region, now Northern Iraq, and found oil seeping out of the ground, as it does today. By the standards of the time he already had enormous wealth at his sword's end, and he was not short of political will. If he had been able to use the oil he would surely have done so, and I would now be speaking to you in a dialect of Macedonian. But he couldn't use the oil, because he didn't have diesel engines, or refineries, or chemists to make diesel-proof synthetic seals, or any of the other complicated objects that are needed to extract, convert, and deliver that energy source as work.

So the question is not *do we have enough energy*, but is it possible to maintain and increase the complexity of the human sphere so that we can use the energy that is actually available?

And on this point there is some ground for concern. For various reasons, climate policy amongst them, governments around the world are attempting to create economic systems where wealth creation is "decoupled" from resource consumption, particularly energy. Simultaneously, they are also driving an energy transition towards high entropy sources of energy, namely renewable flows. The view that I put to you this evening suggests that this vision is deeply mistaken and counterproductive.

The suggestion that we can stay rich without consuming resources, particularly energy, is incompatible with what we know thermodynamically about the world. Even if it was decided to prevent further growth in societal complexity, and some policies do seem to be aimed at that, it would be necessary to continue to consume resources in order to maintain the complexity already present. The people and other engines that compose the giant engine that is our economy must eat.

In any case, because of their capital-intensive, low-energy return, renewable sources are incapable of maintaining the current distribution of complexity. At present most low entropy states are outside the energy sector, and that is what makes us rich. By contrast, in a renewable system most societal complexity must be concentrated in the energy sector itself, as it was and is in organic economies, leaving little over for other purposes.

If amongst those purposes are included a broad range of environmental goals, including air and water quality, and the preservation of biodiversity, not to mention the stabilisation of global temperatures at a level convenient to us, then it would appear to be necessary to accumulate still further complexity in the human sphere, not least to permit mankind to withdraw from large parts of the world, leaving them to other organisms. All that will entail the exploitation of much denser, higher return energy sources than those available from renewables.

So, if there is a green future, it will and must be like all the other improbable futures that men and women have as a matter of fact created for themselves, it will be far from thermodynamic equilibrium. Necessarily, such a future will be energy hungry. We might call it High Energy Environmentalism.