Thermo-economics: Energy, Entropy and Wealth

John Constable explains why energy is so important to economic debate, and why the current government energy policy is unsustainable in the long run.

The government of the United Kingdom has many policies that increase energy costs, including taxes on transport fuels amounting to approximately £27 billion a year (60% of the pump price), levies on consumer electricity bills to fund renewables, currently running at £3 billion a year, and Value Added Tax (VAT) on top of both. The total annual cost of these impositions on energy is set to grow very significantly, largely because of attempts to mitigate climate change, yet government appears unconcerned by the possibility of economic damage, and even argues that the overall effect will be positive. Those of a suspicious cast of mind may well suspect that ministers judge there to be little political risk since the taxes and levies are collected not by the state itself but by commercial entities, who will conveniently take the blame. However, this cannot be the whole explanation, and many in government are obviously sincere in their belief that the economic burdens of the policies are relatively unthreatening, otherwise they would be more concerned, for example, about adding £8 billion a year to the annual cost of electricity in the United Kingdom by 2020 in order to meet the EU Renewables Directive target. However, this paper will argue that, though genuine, the government's relaxed attitude is a dangerous error, and that taxes, levies, and policies mandating the use of comparatively expensive energy sources are not only instantaneously painful, but threatening to prosperity over the long term.

Of the immediate pain, there can be little doubt, and the UK government's own data is sufficient proof. The following tables summarise the Department of Energy and Climate Change's projections of the impact of its policies on electricity and gas prices to domestic households and medium-sized businesses, these impacts being assessed in three fossil fuel price scenarios, Low, Central, and High.

Crucially, even in the high fossil fuel price scenario subsidies will add around a quarter to a third to the price of electricity, suggesting that, in spite of government claims, the policies offer only limited protection against increasing fossil fuel costs. In the low fossil fuel cost scenario, which has long seemed

Year	*Fuel Type Price Category*	*DECC Fossil Fuel Price Scenario*		
		Low	Central	High
2020	Gas price w/o policy	£37/MWh	£50/MWh	£61/MWh
	Gas price w. policy	£39/MWh	£52/MWh	£64/MWh
	Gas price impact	+£2/MWh (+7%)	+£3/MWh (+5%)	+£3/MWh (+4%)
	Elec. price w/o policy	£124/MWh	£150/MWh	£174/MWh
	Elec. price w. policy	£179/MWh	£198/MWh	£218/MWh
	Elec. price impact	+£54/MWh (+44%)	+£49/MWh (+33%)	+£45/MWh (+26%)

Table 1: DECC's estimated average impact of energy and climate change policies on domestic household gas and electricity prices (real 2012 £/MWh, inc. VAT). Source: DECC, *Estimated impacts of energy and climate change policies on energy prices and bills* (March 2013), 28, 89, 90.

Year	*Fuel Type Price Category*	*DECC Fossil Fuel Price Scenario*		
		Low	Central	High
2020	Gas price w/o policy	£22/MWh	£34/MWh	£46/MWh
	Gas price w. policy	£24–27/MWh	£36–39/MWh	£47–51/MWh
	Gas price impact	+£2–5/MWh (+8–22%)	+£2–5/MWh (+5–14%)	+£2–5/MWh (+4–10%)
	Elec. price w/o policy	£66/MWh	£90/MWh	£113/MW
	Elec. price w. policy	£114–117/MWh	£132–135/MWh	£150–153/MWh
	Elec. price impact	+£48–51/MWh (+74–77%)	+£42–44/MWh (+46–49%)	+£37–40/MWh (+33–35%)

Table 2: DECC's estimated average impact of energy and climate change policies on gas and electricity prices (real 2012 £/MWh) to medium sized businesses. Where impacts are expressed as a range the low figures refer to businesses that are not participating in the Carbon Reduction Commitment, and the high figures to businesses that are participating. Source: DECC, *Estimated impacts of energy and climate change policies on energy prices and bills* (March 2013), 47, 48, 91, 92, 93, 94.

probable and now seems likely, they will add over 40% to the price of electricity for domestic households, and over 70% to that for medium-sized businesses. Effects on the gas price are less dramatic, but by no means negligible, ranging from an additional 4% to 7% for domestic households and 4% to 22% for medium-sized businesses.

While DECC, as we have noted, is not deeply concerned about these increases, other departments are attempting to restrain costs, though still without apparent anxiety. The Treasury has recently applied a cap to spending on direct subsidies to renewables, the Levy Control Framework (LCF), but the limit is a very generous one (£7.6 billion, plus 20% headroom, per year in 2020). Furthermore, it has taken no steps to curb the rising overall system costs caused by renewables, which are expected to amount to a further £5 billion a year in 2020 and thereafter.

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The government's attitude may seem negligent, but can be defended by the suggestion that energy is after all just another input, and that economic growth can be maintained in the face of rising energy prices by factor substitution and technological progress, for which there will now be greater incentive. Adair Turner's comments in his 2001 book, Just Capital, are representative of this line of thought. He is here describing how to ensure that energy conservation measures (a significant increase in price for example) do not cause a reduction in productivity (by which he may mean 'production'):

"Energy, along with capital (i.e. machines), is a fundamental driver of productivity – we are more productive and prosperous than 300 years ago because we perform many functions with machines driven by energy. If we use less energy we will need to increase other inputs, e.g. more and better capital investment, or improved technique, if labour productivity is to be maintained." (Adair Turner, Just Capital (Pan Books: London: 2001), 286.)

Even amongst those who are concerned by the short term cost impacts of renewable energy policies, and in particular where these are greater than those affecting competing companies in other jurisdictions (the United States for example), Lord Turner's logic moderates their fears for the more distant future. Nevertheless, there are grounds for thinking that this view is mistaken, and that high energy costs are in fact unavoidably threatening to prosperity due to the close and special relation between energy, wealth and economic growth.

While occasionally raised by outsiders such as the Nobel prize-winning chemist Frederick Soddy, who proposed in his Wealth, Virtual Wealth and Debt (1926) that wealth was "a form or product of energy" and that "the flow of energy should be the primary concern of economics" (p.56), this matter has not been a focus for the mainstream of the field, though some part of the relationship was evident to the founders of the modern discipline, to Smith and Ricardo for example, but their descriptions were weak and failed to persuade subsequent thinkers. Nevertheless, these primitive attempts should be read with sympathy. Correctly realising that a prime mover was required to shape the materials of the world in accordance with human purposes, these early writers proposed labour as a candidate, Smith even stating as an axiom that "Labour [...] is the real measure of the exchangeable value of all commodities" (Wealth of Nations (1776), V,1), a position accepted wholeheartedly by Ricardo (Principles of Political Economy and Taxation (1817), I,i). But this approach did not convince even contemporaries, Malthus being an early critic (Principles of Political Economy (1820), 132), largely because it could not fully explain the wealth created even in agrarian economies, and was obviously quite inadequate to account for the growth observed during the Industrial Revolution. More damaging still, the sleeve-worn heart of Marx's writings is an intensely moralized version of the labour theory arguing for a sweeping dissolution of legal title to an economy's assets and income. This polemical use was far from implicit in the Smithian labour theory, but the association was and continues to be discrediting.

The labour theory therefore declined in influence, partly because of its lack of explanatory power, and partly because of the company it kept. Nevertheless, though Smith and Ricardo had clearly erred, from the perspective adopted in the current account they were wrong only in the sense that labour was, even in Smith's time, an incomplete account. That is to say, labour is only one instance of an energy conversion performing the work (in the strict thermodynamic sense) that delivers wealth and the increase of wealth that we call economic growth. But this connection could hardly have been made early in the century, when thermodynamics was in its infancy, though the general importance of energy was, of course, increasingly understood, by Jevons for example, who clearly recognised that it was no ordinary input:

"Coal in truth stands not beside, but entirely above all other commodities. It is the material source of the energy of the country – the universal aid – the factor in everything we do. With coal almost any feat is possible or easy; without it we are thrown back into the laborious poverty of early times." (W. S. Jevons, The Coal Question (1865; 3rd ed. 1906), 2.)

However, by the time that Jevons wrote these words the beginnings of the marginalist reform of economics were stirring, not least in Jevons' own thought, and the significance of his remarks on energy was obscured and the opportunity to reform the labour theory lost. In any case, without the context of thermodynamic principles his insight could not be developed in any thoroughgoing way. But we are more fortunately situated, and can give richer causal accounts, for example of the importance of dense and plentiful energy stocks such as coal in sustaining the Industrial Revolution, in other words in preventing the economic stagnation predicted by Smith, and actually experienced by the Dutch in the 18th Century, who in spite of a modernised society could not support further rapid industrialisation because their energy source was the much less satisfactory peat. As Wrigley's study, Energy and the English Industrial Revolution (2010), indicates, it was coal that permitted humans to "escape from the constraints of an organic economy". Civilisations had of course existed on the basis of relatively thin organic energy flows, rather than the rich stocks of fossil fuels, and their cultural and other achievements are remarkable, but, Wrigley observes, "the bulk of the population was poor once the land was fully settled; and it seemed beyond human endeavour to alter this state of affairs." (p.239):

"The 'laborious poverty', in the words of Jevons, to which most men and women were condemned did not arise from lack of personal freedom, from discrimination, or from the nature of the political or legal system [...] It sprang from the nature of all organic economies. [...] the plant growth in question represented the bulk of the sum total of energy which could be made available for any human purpose." (p.239)

On reflection, and adopting a framework consistent with thermodynamics, we can see that this is unsurprising, since wealth is created by using energy to introduce improbable order into the world, in other words a reduction of entropy in one part of the system at the expense of a greater increase in entropy in another. This valuable order can be analysed both as complex structure (a refrigerator for example) and timeliness (the cool glass of water in the desert is valuable because it is improbable in that location at our hour of need, and only the use of energy can make its delivery certain).

This view, which is as much a way of describing economic history as anything, sees improbability (complexity and timeliness) as the common property of all valued outputs, and indeed of all valued capital. It is the common property not only of tools and machines, but also bridges and improved land. Perhaps less obviously it is also a property of ideas and the mental and external representations that carry them, to say nothing of the institutions and traditions in which these representations are themselves further organized.

Low entropy structure is also required of many inputs to our economic activity, and, where such order is lacking, energy is used to rectify that failing: if a raw material is only found in a dispersed condition, energy will be used to concentrate it, though this of course makes it comparatively more expensive. Some organic products, meat and timber for example, are found in a state of low entropy, but modification is almost always necessary to further structure and then deliver such goods in accordance with our purposes.

In other words, the entire human sphere, and indeed that of much life round it, is situated far from thermodynamic equilibrium, and it is the slowly accumulated results of energy use that have brought us to that happy position, surrounded on every side by complex goods delivered in a timely fashion, the whole network being extremely improbable. That is to say, previous energy consumption is rendered in the current state of affairs as the improbable complexity that we value. Of course, continued energy use is also needed to activate many of these goods, and also to repair and maintain existing complexity, which is forever declining towards equilibrium. Furthermore, since there is no obvious limit to the convenient modifications that can be made to the world, more energy is employed to augment the existing network of complex structures, making it still more remarkably well-adjusted to human requirements.

This improbable order has been steadily accumulating over a period extending far back into the prehistory of our species, with much of it, our bodies and the psychological complexity of our minds for example, being in large part the result of evolution by natural selection. The non- or extended phenotypic material, with which we are principally concerned here, is the product of the more recent economic phase, which is mostly historical but not entirely so.

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The order of this latter phase, order which I shall now call "capital", giving that term the very broad sense indicated above, is long-lived and ubiquitous, being found not only in the fabric of agricultural land, and the infrastructure of the built environment, much of great age, but also in our systems of symbolic representation, in the powerful models of the world that we have built with those systems, and in the laws and institutions that govern relations between individuals and facilitate co-operation and exchange.

This accumulated and inherited wealth is so familiar a background to our daily activities that we tend to neglect it, or at least we regard it as a minor contributor to contemporary output. But the truth is that we are critically dependent on this legacy, and while individual items of this wealth can readily be replaced when destroyed or consumed, if obliterated instantaneously and in very large part we would struggle to repair the loss. This is obviously true of the structure of agricultural land and other infrastructure, but particularly true of intellectual capital and social or institutional complexity, for in combination with sufficient free energy such wealth permits the replacement of other capital lost, perhaps as a result of natural disaster or war. Mill notes this fact in his Principles of Political Economy where he dismisses any surprise that countries can "recover rapidly from a state of devastation" by observing that what is destroyed in such cases is only one part of the resources of an economy:

"[…] An enemy lays waste a country by fire and sword, and destroys or carries away nearly all the moveable wealth existing in it; all the inhabitants are ruined, and yet in a few years after, everything is much as it was before. […] There is nothing at all wonderful in the matter. What the enemy have destroyed would have been destroyed in a little time by the inhabitants themselves. […] The possibility of a rapid repair of their disasters mainly depends on whether the country has been depopulated. If its effective population have not been extirpated at the time, and are not starved afterwards, then, with the same skill and knowledge which they had before, with their land, and its permanent improvements undestroyed, and the more durable buildings probably unimpaired, or only partially injured, they have nearly all the requisites for their former amount of production." (J.S. Mill, Principles of Political Economy Bk 1, Chapter V, Paragraph 7 (1848) ed. V.W. Bladen and J.M. Robson (University of Toronto Press: Toronto, 1965; reprinted by the Liberty Fund 2006), pp.74-75.)

In other words, our economies are capable of satisfactory self-restoration provided that the damage is shallow. By contrast we can easily imagine the difficulty of recovering should the intellectual and institutional capital of an economy be substantially eradicated through destruction of the relevant parts of the population. Fortunately, total destruction is very unlikely to affect the whole of even a relatively small economy, and repair, as Mill observes, will be possible since so much of the thermodynamic order, the wealth of the country, survives even very severe blows.

But the fact that our economies are robust should not lead us to think that they are invulnerable or that damage does not bring suffering. Even a slight shift of the human economy towards thermodynamic equilibrium will be painful for many and fatal for some, as Mill's example reminds us. Nevertheless, for a very long period, several centuries in fact, the world's major economies have experienced no serious or long term setbacks, and in spite of terrible perturbations there has been steady growth in the complexity of capital networks with consequent improvements in human well-being, such as better health, increased longevity and reduced rates of child mortality. Our ability to maintain and augment these capital structures, as Wrigley shows, is a straightforward consequence of replacing the low density, expensive, organic energy flows that have sustained human economies over most of our history and pre-history, with dense, cheap energy, in other words energy obtained from processes that have a high energy return on energy used in generation, with the large surplus being made available for the creation of wealth. By contrast, when the energy return on energy invested is low, as it is in the organic economy, there is little surplus left over for uses other than generating more energy. In such a situation, where most of the available timely complexity is concentrated in and on the energy sector itself, there is only a thin margin for immediate consumption or from which capital can be accumulated. Consequently, the rate of non-energy sector accumulation is slow, and if the organic energy supply is relatively stable, as it is in a system where the resources of the land are fully exploited (to use Smith's term), then the rate declines over time as progressively more of the energy surplus is taken to repair existing wealth. Without an expanding energy supply stagnation seems inevitable.

> "Without an expanding energy supply, stagnation seems inevitable"

It was the development of coal in the presence of already accumulated stocks of complex intellectual and institutional capital that changed this by making available a low entropy stock that delivered a great surplus of energy over and above that invested in its extraction and delivery to consumers. As Wrigley notes, a worker in the coal industry was a hundred times more productive of energy than a labourer in the agricultural sector, which had hitherto provided almost all the energy required (Energy and the Industrial Revolution, p.244). Indeed, it was that concentration of resources in the agricultural world – two thirds of the workforce worked on the land – that accounted for the extreme personal and political power of the landed aristocracy and probably explains the continuing romance of that class to our own day, for such levels of absolute and relative wealth and absolute and relative socio-political power are rare in human history, making them an attractive focus for daydreamers and fantasists.

The productivity of coal transformed the economy and the political balance, and for the better. Energy was now cheap, which is to say that there was more energy available for purposes other than the production of energy itself, and the power of land and its owners declined as it ceased to engross and produce so large a share of the available economic resources. With the large surplus energy of coal came general prosperity; indeed, the size of the surplus of energy available over that invested in its generation is the major substantive content of the proposition that energy at a particular time is cheap. Conversely, when we say that energy is expensive we are indicating that the resource requirement of energy production is high, and that the energy returned on energy invested is low. And of course, when energy is cheap the goods and services facilitated are also cheap, partly because they are plentiful, but also because the rendered energy component in those goods is low in cost. To put this point another way, the energy rendered in a good is not only the energy needed for its immediate production, it is the energy rendered in the energy itself.

Thus, a forced energy transition against the cost gradient, as is currently proposed by several OECD governments, drives energy resources into the energy generation sector itself, reducing their availability for other purposes. The smaller surplus of energy is now more expensive, and as this surplus is used to repair and refresh capital, so the use of that capital itself becomes more expensive, an effect that will gradually but inevitably reduce general prosperity over time.

Now some might reject this position, and observe that history endorses the view taken by Adair Turner and many others, namely that rising energy costs will stimulate innovation and efficiency, and that there is consequently relatively little to worry about. The first oil shock, they might say, was a salutary and improving experience that motivated intrinsically worthy energy efficiency improvements that would otherwise have been neglected.

However, such an argument would be misleading. The oil shock was of very short duration, meaning that most investments in new and repaired capital could be deferred until prices fell. If the high prices had continued, capital investments would have become unavoidable, and the high prices would have then increased the cost of using those stocks, with long-term economic effects. Moreover, it was possible to mitigate the effects of the shock by substituting existing intellectual and mechanical capital for immediate energy (for example, in the improved efficiency of conversion devices). In other words, it was possible to reduce the consumption of high cost energy only by deploying the low entropy capital stocks rendered from cheap energy consumption in the past. If the high prices had persisted and been rendered in the country's capital stocks through maintenance and replacement, the protective potential of this substitution would have disappeared over time.

This buffering effect is part of the explanation of the otherwise remarkable fact that while several European states, the United Kingdom amongst them, have recently inflicted very high additional cost burdens on their economies in order to support renewable energy, there has been little protest. Since 2002 the UK alone has already paid well in excess of £10 billion in additional cost to support investment in renewable electricity generation, and this total will rise sharply over the decades to come. The cumulative burdens in Denmark, Germany, and Spain are and will be still greater.

Damaging though this subsidy is, the impact has been mitigated since so much of our current capital was rendered from cheap energy, and consequently the cost of using that capital stock, substituting it for energy for example, is relatively low. But this situation cannot continue indefinitely. The policy-induced energy cost increases are a chronic presence not an acute shock; even assuming that no further generating plant is constructed in the UK after meeting the 2020 renewable electricity target, the subsidy entitlements created up to that time will persist for another two decades. Indeed, the cumulative subsidy burden between 2002 and 2040 will amount to about £160 billion. Unavoidably, this burden will in part be rendered as new and repaired capital, the costs of use for which will necessarily be higher. It is therefore to be expected that non-energy input costs should now begin to show a steady upward trend as high energy costs work their way through, entailing steady reductions in standard of living as more of the wealth of the economy circulates within the capital of the energy sector and less in other sectors outside it. This effect may be first evident in Germany, where deployment of subsidized renewables is so far ahead of any other major economy, but may also be significant in the United Kingdom which is entering a phase of major infrastructure renewal, a clearly unfavourable moment to have high energy costs.

However, the accumulated wealth on which the European economies rest is very substantial and the damping effect of this capital may mean that the harm will not become salient for some time; Britain, after all, is still, even now, benefiting from the rendered energy of cheap coal consumed in the nineteenth century. However, a decline in standard of living is unavoidable, even if postponed, and the longer such energy price impositions are maintained the more difficult it is to remedy the situation; even if tax on petrol and diesel were to be reduced to zero today, the cumulative tax burden so far levied will in part remain as embedded cost in the miscellaneous capital stocks of the economy, and even assuming that very cheap energy is available would not be flushed out for some decades.

It seems, therefore, that any comfort taken from the concept of capital substitution in the presence of policy-induced high prices is false comfort. Energy is not just another input: it is rendered in all other inputs, and consequently it can never be too cheap, for it is cheap energy that makes us wealthy. Taxes such as fuel duty are economically threatening, and deserve more serious discussion, but a policy-mandated shift to renewable energy in spite of its cost is still more dangerous, since it will not only reduce prosperity but will concentrate capital resources in the energy sector with a consequent imbalance of socio-political power that is likely to be highly controversial and potentially destabilizing. ■

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