General Purpose Material – How to evaluate the importance of oil in economic growth?

Over-dramatizations

The inspiration for this paper is a classic of economic history from 1964, *Railroads and American Economic Growth: Essays in Econometric History* by Robert William Fogel. Fogel demonstrated that the building of railroads was not as indispensable for American economic growth as was implied in the speeches of railroad directors or in the writings of economic historians. This tendency to use certain expressions implying the overwhelming importance of one's own particular field is a common one, and it certainly exists in the field of oil. In Appendix 1 a sample of oil quotes is included, dating between 1914 and 2006, with an 1865 quote about the importance of coal thrown in for comparison. Most of these quotes give the flavour of over-dramatization.

The label 'Age of Oil' seems to have gained a sure footing alongside 'Coal Age' and many other various 'ages' in history. Because the expression has a long history and has recently appeared even in many book titles, there is no point in questioning its legitimacy.

Some expressions in Appendix 1 are just vague figures of speech ('oil had fueled economic growth'; 'from coal-fired growth to a predominantly oil-based economy'), although when reading a statement such as 'Oil is the most vital resource of our time' one might just as well substitute 'oil' for 'water' or even 'sunlight' or 'knowledge'.

Instead, assertions like 'the industrial nations that had based their economic growth upon oil' and 'oil, which has contributed most to economic growth this century' not only present a description of history but appear to suggest an explanation for economic growth. They invite one to compare oil to coal with its reputation for playing a crucial role in the British Industrial Revolution, the very beginning of sustainable economic growth in the West.

The causes of the Industrial Revolution continue to be discussed among economic historians, and one controversial issue is the role of coal. It is an analogous case to the discussion about the role of oil and an example of the significance of distinction between description and explanation.

Description vs. explanation

In E. A. Wrigley's book (1988) on industrial revolution a key concept was 'mineral-based energy economy'. For him it was the later of two modes of economic growth of industrial revolution in England. 'The period down to the early nineteenth century may be regarded as a period in which the sources of growth were mainly those of an advanced organic economy. Thereafter the mineral-based energy economy was increasingly dominant as the vehicle of growth' (p. 17). Coal, which as a stock of energy alleviated the pressure on the limited resource-flows in an organic economy, was of 'fundamental importance in promoting economic expansion' (p. 77). Wrigley's conclusions have been interpreted to mean that coal, as part of Britain's geographical advantages, explains the British Industrial Revolution (see e.g. Engerman, 1994: 113 and Pomeranz, 2000: 59 approvingly; Gregory, 1990: 360-372, Mokyr, 1999: 32-34, and Stobart, 2004: 12-13 debating the validity).

In a later article by Wrigley (1994) it becomes clear that his line of argument is based mainly on counterfactual reasoning about the sustainability of economic growth: 'If, on the other hand, it is unrealistic to suppose that the use of the muscular energy of man and beast plus the fullest exploitation of wind and water power would have sufficed to sustain exponential growth, then the fact that coal was present and accessible in amounts amply sufficient to meet demand must be a necessary condition for the growth that took place' (p. 37). However, as he himself wrote in the same article: 'To show that a particular change was a necessary condition for an industrial revolution is not, of course, to show that its occurrence was central importance to the explanation of the phenomenon' (p. 35).

A key sentence in this discussion about coal and the causes of the Industrial Revolution is one of Joel Mokyr's: 'In other words, it is possible to accept Wrigley's (1987) view that substituting coal for wood was an important part of the transformation of Britain, without attributing undue significance to the geographical accident of the presence of coal in Britain' (Mokyr, 1999: 32-34). One can ex post estimate the change of values of wood and coal consumed in the economy, and the share of their value of total change of input values gives you a measure of their importance in the change: a partial description. However, that number does not give you a measure of significance among the causes of the change, in the explanation.

Focus on tehnological change

Some confusion in the discussion above comes from the difference in focus between Wrigley (1988 and 1994) and conventional wisdom presented by Mokyr in the article 'Industrial Revolution' in *The Oxford Encyclopedia of Economic History* (2003). For Wrigley 'industrial revolution' described the changes of the eighteenth and nineteenth centuries, whereas in the *Encyclopedia* the 'term *Industrial Revolution* is normally reserved for a set of events that took place in Britain roughly from 1760 to 1830'. Wrigley's approach is more at macroeconomic-level (e.g. growth of national income per head), higher aggregate-level (total coal or energy consumption), and extends to a later period. In Mokyr's approach the more concentrated focus on technology, the shorter period, and more emphasis on Industrial Revolution as 'a localized affair' reveal more clearly its real essence: 'Technology was at the core of everything.'

Coal's association with technological progress introduced during the Industrial Revolution is mainly with the steam engine. However, during the Industrial Revolution itself, steam power was adopted only slowly. For instance, in the mechanization of the cotton industry – 'traditionally seen as the pacemaker of the Industrial Revolution' –, water power competed succesfully against steam for some new large mills even in the 1790s, and provided most of the power until after 1820 (Gregory, 1990: 371). Another case of association with technological progress was the iron industry where coal's chemical properties were important. There was not much change in the sector itself: '... except in the drainage, the coal industry was far from the leading edge of technological change' (Wrigley, 1994: 34-35). Other associations with productivity growth can be identified, but are difficult to quantify. When coal was increasingly used as a substitute for firewood in cooking or domestic heating, the effect on productivity of the economy came via a finer division of labour (assuming that digging for coal was done by the supplier rather than the final user, for instance when the buyer had moved from the countryside to the town). Coal had a similar effect on productivity growth as the expanding source of heat in industrial processes, with more economies of scale.

The catalytic power of the Industrial Enlightenment

Taking the long view, the label 'mineral-based energy economy' seems to be out of focus in two ways. Firstly, it concentrates on one type of fuel, although the really radical and crucial change was the discovery that heat can be converted to movement, to power which can do work (both in the physical sense and – through mechanization – economic work). Steam technology can also be utilized by other than 'mineral-based' fuels (e.g. in the industrialization of the USA substantial amounts of firewood were used to power railroads and steamboats long into the nineteenth century). Secondly, the label implies a critical significance of sustainability. Although in Wrigley's counterfactual reasoning growth with an organic energy base was not entirely out of the question, it was 'difficult to picture' (Wrigley, 1994: 37). For Mokyr 'the Industrial Revolution was above all an age of rapidly changing production technology propelled by technological creativity' (Mokyr, 1999: 18). He has traced the origins of this creativity to the Baconian programme of the seventeenth century and to the eighteenth-century Enlightenment in the West which carried out this programme (Mokyr, 2005). Because 'the taproot of modern economic growth' was based in so fertile a soil, we can sketch an alternative energy economy in a reasonable counterfactual past with confidence, especially as we have already seen so many possible alternatives actually developed.

There are some useful lessons to be gained from this discussion about the case of coal for analyzing the case of oil. First, to avoid fallacies of energy generalization one needs to build the analysis from the types of service provided and their link to productivity growth. Secondly, for long-term economic growth per capita the main credit goes to cumulative technological progress (and more to the knowledge producers of previous generations than to ours).

Fallacies with the total energy consumption

One might think that a simple calculation using energy statistics, giving the share of oil in total energy consumption of an economy, would establish its importance. But that would be a mistaken view in many ways. Total energy consumption is a very abstract concept. Compare it to an analogical concept of total raw materials consumption calculated according to the physical weight. From the economist's point of view, this does not make much sense because different materials are used for so many different purposes, and materials can be substituted for other materials that have a totally different weight e.g. because the economic value comes from the surface covered by the materials in question (Lavonius, 1992). Although different energy uses can be measured in equivalent units according to their heat content, all tonnes of theoretical oil equivalent in the economy are not direct substitutes for each other, and do not add value to the GDP with similar weight per thermal content.

Because in physics various forms of energy can be measured with same unit and in a theoretical conversion total national energy consumption can be seen as an input of mechanical work to its economy, from time to time an economist finds it ingenious to explain GDP growth with the growth in employing this fascinating energy. Statistical correlations are high. This is one kind of delusion, because only in very primitive circumstances total economic output is a material product of mechanical work alone. Work in physics ≠ work in economics. Anyone who has practical experience of serious work for long-term energy demand forecasts would not begin by extrapolating the total energy consumption at the highest aggregate level.

Towards more systematic data on technical energy efficiencies

In the long run the advancements of the technical properties of energy services providing equipment or building have had essential effects on energy demand. Unfortunately, systematic statistical data on technical effects proper are scarce. There are again easy numbers at the highest aggregate level, i.e. measuring changes in total primary energy use per unit of gross domestic product. But this macro view of energy intensity gives an inadequate picture, because it does not separate the impacts of changes of the volume of various activities, of their structure, and of their energy intensity. In their internationally comprehensive analysis Lee Schipper and Stephen Meyers made this decomposition by building a bottom-up system at a meaningful level of disaggregation (Schipper and Meyers, 1992). They pointed out that in this analysis energy intensities depend not only on technical energy efficiency but also on the operation of equipment or building (load factors, heating habits etc). Roger Fouquet and Peter Pearson concentrated more clearly on technical efficiencies (although in one country only) in their historical research on long term (several centuries) developments in energy service provision of transport and light (2003 and 2006).

Lee Schipper later continued his approach as the prime mover in developing a systematic data collection for a hierarchy of energy efficiency indicators in an ongoing project of the International Energy Agency (see results e.g. in IEA, 2004). Now the value of and the need for disaggregated statistics on energy efficiencies seems to be recognized worldwide. Additional significance has come from environmental impact of energy use and consequently CO2 emissions have been incorporated in these indicators. However, to build a coherent international system is not easy. For an overview of the present situation see papers at recent IEA workshops (IEA, 2006).

Eleven years ago I presented an idea of 'a macroeconomic indicator of progress in energy efficiency', analogous to the common consumer price index, based on periodic samples of various technical energy properties, and aggregated according the economic (monetary) value of the item (Lavonius, 1995). This suggestion appears to be quite idealistic set against the background of the above mentioned difficulties in the IEA approach. However, aggregation according to the monetary value of the item seems to be alien in the IEA approach. In this respect the Fouquet and Pearson approach is nearer economic history, because they put more emphasis on the value of the energy service. (In their results one finds, for instance, oil in the history of artificial lighting, first as kerosene and later as one source of electricity.)

Growth accounting and counterfactuals

One logical way to put more emphasis on economics in describing the development of energy demand as part of national economies would be to express total energy consumption calculated in monetary units, using fixed prices to get 'Economic Volume of Total Energy Consumption' (Lavonius, 1992) and current prices to compare total energy costs with the value of GDP. In calculating all totals with monetary units the anomaly of including non-energy use of oil according to its theoretical heat content would disappear.

Growth accounting (i.e. trying to measure the contribution of technical change to economic growth by calculating so called *total factor productivity* as a remainder after input changes of capital and labour) seems to be a controversial method. However, growth accounting has a long history (also in energy economics), and recently e.g. Nicholas Crafts seems to have obtained interesting and reasonable results in 'Steam as a General Purpose Technology: A Growth Accounting Perspective' (2003). For evaluating the importance of oil, growth accounting approach should be seriously considered, too.

A counterfactual can be reasonable, entailing a thought experiment that is researchable (instead of e.g. 'What if the industrial revolution had not happened?' (McCloskey, 1987: 17). It would not be worthwhile to totally eliminate oil in a thought experiment, in order to check whether Fogel's conclusion that no single innovation was vital for economic growth during the 19th century applies also to the 1859 discovery of how to produce crude oil in abundant quantities. Instead, one could speculate about the timing of that event (obtaining liquids and chemicals from coal as an alternative) or about the price trends of oil.

General Purpose Material

A very persuasive case for the usefulness of the concept *General Purpose Technology* (GPT) in explaining long term economic growth was recently presented in a comprehensive book by Richard G. Lipsey, Kenneth I. Carlaw, and Clifford T. Bekar (2005). In their definition important characteristics of a GPT are: it initially has much scope for improvement and eventually comes to be widely used for a variety of purposes, and creates opportunities for new innovations which then, in a long-lasting chain reaction, again creates opportunities for new innovations (spillover effects). To be identified as a GPT, a technology must possess each of the four characteristics in abundance.

Crude oil is not included in their list of 24 transforming GPTs, although it shares the characteristics of a GPT except one: it is a material, not a technology. But they already defined one new concept: the *General Purpose Principle* (to take into account e.g. mechanisation). It seems legitimate to suggest another concept for a material which is widely used for a variety of purposes, with scope for technological development and creating opportunities for new innovations. Some technologies which could almost be counted independently as GPTs, have strong links to oil: chemical engineering, the catalytic process, transforming material at the molecular level by cracking and polymerization, or plastics which can be compared to bronze, already counted as a GPT. It certainly looks promising to see oil as a *General Purpose Material* (GPM) and to apply also this evolutionary approach to research its role in long term economic growth.

By-products all – inequal sharing of common costs

Crude oil shares with trees (or wood as another GPM) some characteristics of product price formation. Money derived from selling tree trunks pays almost all the common raw material costs. Tree branches or products made from them can be sold at a lower price per cubic metre than trunks. In a similar way, crude oil is a mixture of many different hydrocarbons. Producing the most valuable petroleum product inevitably yields other petroleum products. All these petroleum products have their individual markets and prices – and 'each product sells at the price its market will bear' (Frankel, 1968: 60). The cheapest one, the residual heavy fuel oil, has to be sold – usually at a lower price per ton than crude oil – but in any case it contributes towards paying some part of the necessary common costs. (From early on, in this kind of biased competition coal did not stand a chance, especially after the growth of gasoline demand for cars begun.)

Due to their common raw material base, changes in the demand and price of one oil product always affect the price of others. The structure of production at refineries can be influenced either directly by shifts in refinery operations and crude grades, or by the use of additional downstream refining units and – in the longer term – by technical improvements to increase the share of the most valuable products.

Since 1965, when the share of fuel oil in the product structure of world oil consumption was already clearly smaller than the original percentage of the days of simple crude oil distillation, the share of fuel oil has diminished considerably, from 26.5 % to 12.3 % in 2005 (BP, 2006). The mainspring of this change has been the improvements and diffusion of Fluid Catalytic Cracking technology, mainly due to being able to process heavier and heavier oils to lighter products (Enos, 2002).

The increasing use of oil products improved productivity in national economies via many routes, differing in their impact on productivity, not only as various liquid or gaseous fuels but also as lubricants, detergents, bitumens for road surfacing, and feedstocks for fertilizers, petrochemicals, plastics, rubbers and fibres. It is also associated with some lines of technological progress due to the special characteristics of crude oil. For instance, the availability of feedstocks seeking valuable forms of application has been seen as a driving force in the development of the petrochemical industry (Spitz, 1988: 514-515).

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Appendix 1

A sample of quotes on the importance of oil
While the nineteenth century will be known to history as the Coal Age, the twentieth century certainly will go down to posterity as the Oil Era. Oil is becoming more and more indispensable to our complex social and industrial existence; in fact, it is almost impossible to mention a phase of human activity in which it does not play a more or less prominent part in one form or another. – Frederick A. Talbot (*The Oil Conquest of the World*, 1914, 1)

There is no doubt about our absolute and complete dependence upon oil. We have passed from the stone age, to bronze, to iron, to industrial age, and now to an age of oil. Without oil, American civilization as we know it could not exist. – Harold L. Ickes, 'After the Oil Deluge, What Price Gasoline'? *Saturday Evening Post*, February 16, 1935, pp. 5-6 (quoted by Daniel Yergin in *The Prize*, 1991, 254)

Without oil modern civilization would be extinguished and the world, especially the industrial and developed world, would be covered by pitch darkness. ... Oil in our time is the main instrument of economic, social and political change. – Mana Saeed Al-Otaiba ('The Role of Oil in Civilisation' in *Essays on petroleum*, 1982, 163)

'Oil power' loomed very large in the 1970s, catapulting states heretofore peripheral to international politics into positions of great wealth and influence, and creating a deep crisis of confidence in the industrial nations that had based their economic growth upon oil. – Daniel Yergin (*The Prize: Epic Quest for Oil, Money and Power,* 1991, 13-14)

In the 1950s and 1960s, cheap and easy oil had fueled economic growth and thus, indirectly, promoted social peace. – Daniel Yergin (*The Prize,* 1991, 653)

Indeed, with the fate of the planet itself seeming to be in question, the hydrocarbon civilization that oil built could be shaken to its foundations. – Daniel Yergin (*The Prize,* 1991, 780)

For ours is a century in which every facet of our civilization has been transformed by the modern and mesmerizing alchemy of petroleum. Ours truly remains the age of oil. – Daniel Yergin (*The Prize,* 1991, 781)

Oil is an integral part of that body of modern technology, which, by easing the physical burden of work and reducing the amount of time spent on work, transport, and travel, has been a major factor in the economic development of the twentieth century. – Jaakko Ihamuotila (Foreword 'Neste today' in Kaj Hästbacka (ed), *Neste: from Oil to Plastics*, 1993, 5)

In the past, market forces have enabled the world to effect a shift from coal-fired growth to a predominantly oil-based economy. – Dr Subroto ('The road from Rio – OPEC's view', 7 September 1993, Netherlands Energy Research Foundation Seminar, in *Viewpoint 1992-94. A selection of speeches by Dr Subroto, Secretary General of OPEC*, 1994, 248)

The world is confronted with irony that oil, which has contributed most to economic growth this century, is likely to be taxed to prolong the life of unproductive sectors of the economy. – *Petroleum Argus* (Editorial 'The unworkable tax' (27 June 1994)

Oil is the most vital resource of our time. – Leonardo Maugeri (*The Age of Oil. The Mythology, History, and Future of the World's Most Controversial Resource*, 2006, Beginning of the book description)

A quote on the importance of coal in 1865
Day by day it becomes more evident that the Coal we happily possess in excellent quality and abundance is the mainspring of modern material civilization. ... But coal alone can command in sufficient abundance either the iron or the steam; and coal, therefore, commands this age – the Age of Coal. – W. Stanley Jevons (*The Coal question. An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal-mines*, 1865, 1-2)