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***Energy and Natural Resource Dependency in
Europe, 1600-1900***

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Abstract

This paper takes a historical perspective on the role of resource endowment in economic development, examining the leading economies of the early modern era, the Netherlands and England; the first case largely dependent on imports for raw materials, while the second enjoyed the boon of much larger indigenous energy reserves. It argues that locational advantages were an essential part of the story of early modern growth: in the Dutch case, access to factor markets and trade routes; in the English, these combined with natural resources. There is little evidence that the benefits of growth were spread to the periphery, but neither did inequities in growth patterns contribute significantly to institutional backwardness and rent-seeking in the periphery.

Keywords: Resources, Energy, History, Growth, Netherlands, Britain

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Introduction

To an earlier generation of economic historians, it was self-evident that modern growth was predicated on favourable resource endowments and the technology to exploit them. The precocious English use of coal and development of associated technology, such as the steam engine, represented the exemplary case (Pollard, 1981; Wrigley, 1988). Yet more recent developments have shaken that belief. It has been a striking characteristic of recent economic development and the international division of labour that economies heavily dependent on natural resource exploitation and export suffered from sluggish economic growth. One can speak now of a 'resource curse' (Barbier, 2005). The importance of natural resource availability for economic success is now treated as a special case, as in the expansion of American economies in the period 1870-1914 (Findlay and Lundhal, 2004), or as having rested on unequal exchange, facilitated by the use of military might to obtain colonial resources at low cost (Pomeranz, 2000). In the case of England, reassessment of historic growth rates has played down or eliminated the special character of the Industrial Revolution (c.1770-1830), making the very process of development appear to be more incremental in character and less closely related to the employment of particular technologies or energy sources (Crafts, 1985; Crafts and Harley, 1992; Crafts, 2003).

Hence relative natural resource abundance may now be viewed as detrimental to development (the so-called 'Dutch disease' as path dependency), while relative scarcity may actually prompt benefits through 'induced innovation' and substitution to less resource-dependent activities. A belief in the fundamental substitutability of factors of production in the long term has shifted attention away from resources as a major developmental issue for many economic historians. If factors are relatively easily substitutable, then relative backwardness must be explained by variant institutions or preferences (e.g. North, 1973; Clark, 2007). While the study of the material world is increasingly dominated by ecological and evolutionary approaches that argue that substitutability is frequently not possible, and that the keystone nature of certain species and processes (sometimes known as 'control parameters', variation in which prompts non-linear behaviour) are what defines particular ecologies and prompts extinction, neo-classical economics has by and large been happy to abstract humanity out of these constraints.

Recent studies have also given more prominence to the importance of the service and commercial sectors in promoting growth, an approach that can be associated with a belief in the 'dematerialisation' of the economy: that is, the idea that above a certain level of income, each unit earned requires progressively less material or energetic input. This seems to be reflected in the fact that the primary producing sectors are small in most developed economies, and that only a small amount of national expenditure is devoted to the energy and raw materials sectors; a far cry from the pre-industrial norm, where a very high proportion of all economic activity was devoted to obtaining food, fodder and fuel. It may be hoped that later developers can circumvent the pattern of early stages of development being resource-intensive (associated with the 'environmental Kuznets curve'), and benefit from growth based on knowledge and cutting-edge technology (Romer, 1990; Kander, 2007). Certainly the 'energy intensity' (energy consumption/GDP) of economies has tended to be stable or to fall in the very long run, although everywhere aggregate energy consumption has continued to expand with growth (Gales et al, 2007; Kander, 2007). The rise of resource inputs tends, however, to be seen as a consequence, rather than a cause, of growth.

This paper revisits the nature of early economic growth, with two case studies of natural resource use from the early modern era. The first case is the Netherlands, which some would argue to have been 'the first modern economy' (de Vries and van der Woude, 1997). The Netherlands, especially its highly urbanised and industrialised western province of Holland, was clearly not a region well endowed with any natural resources, aside from peat supplies. Yet for 200 years, from the late 16th century, the Dutch economy earned the highest per capita incomes in Europe and was the undisputed centre of the European carrying trade, industrial and technological progress, and a major processing centre for colonial goods (van Zanden, 2000; van Zanden, 2004; Allen, 2001; Ormrod, 2003). Dutch growth promoted early forms of economic integration around the North Sea and the Baltic in a system of core-peripheral relations that pre-empts in many regards contemporary globalisation (Wallerstein, 1974; van Bochove, 2008). Despite the relatively low level of technological progress and consumption by later standards, which necessarily limited the scope for large income differentials (Malanima, 2002), the Dutch long maintained an economic lead over neighbours, despite heavy dependence on the input of raw materials: foodstuffs, timber, wood byproducts, metals, and fibres. Why were the Dutch able to maintain a lead for so long? Was Dutch success in fact an early example of 'dematerialisation'? And did putative Dutch modernity also lead to the structural retardation of regions supplying natural resources?

By the early 19th century, Dutch economic leadership was being supplanted by English: not only in terms of Europe, but the world. English industrialisation was long characterised by the export of raw material or low-value products, but during the 17th and 18th centuries it underwent a transformatory process of improving labour productivity in agriculture, import substitution, achieving technical leadership in low quality consumer goods, and a vigorous re-export trade in colonial goods (Wrigley, 2004; Ormrod, 2003; Matthias, 1984). It became heavily dependent on coal, in both the household and industrial sectors, and some would argue also on 'ghost acreages' obtained via colonial expansion and the slave trade (Pomeranz, 2000). Yet much of its raw material and especially energy needs were met domestically. England became a technological leader in some industrial sectors, notably with the epochal transformation of thermal energy into kinetic energy achieved by the steam engine. This growth was clearly energy intensive – increasingly so, up until the 1880s. Is England thus an exceptional case of natural resource-based growth and economic leadership, rather than the exemplary case for industrialisation, as understood by earlier generations of economic historians (Warde, 2007; Rostow, 1953)?

Unlike today, but rather like most of the world until well into the 20th century, early modern Europe was largely an 'organic economy'. That is, nearly all of its energy came from the process of photosynthesis in plants transforming insolation into forms useable by people: food, fodder for animals, and firewood. Energy supply was thus spatially diffuse, and growth required territory (Wrigley, 1988; Siefertle, 2001). The advent of fossil fuels abolished the 'photosynthetic constraint': as well as providing vastly greater reserves of energy that could be rapidly consumed, their sources were located in more concentrated reserves and could be exploited without competition for other land uses, encouraging concentration with the benefits of economic density and spillovers (known as 'punctiform growth'). This also promoted a subsequent march towards the use of fuels of ever greater 'quality', with a high energy content by mass, and especially those that can be used in liquid form in transportation. We may ask how important such resource-based concentration could be for early modern success. But we may also point to the re-emergence of an areal energy economy, in the shape of biofuels and to some degree other renewable sources such as wind farms. Electrification may be considered a highly efficient form of energy transport

(despite losses in both generation and transmission), and hence modern areal economies may operate under much lower constraints than historic organic ones. Nevertheless, can we learn lessons from the areal, and more particularly the organic, economies of the past?

The Dutch 'Golden Age' and natural resources

During the 17th century, the Dutch merchant marine amounted to some two-fifths of that of the entire continent of Europe. The Dutch population amounted to around two percent (van Zanden, 2000). The United Provinces were a commercial superpower that dominated the carrying trade, but the bulk of that shipping was still employed quite locally in the near European trades to northwest Europe, and especially in the timber trade and grain trade of Scandinavia and the Baltic. The grain trade was considered the 'mother trade' and by the early 17th century supplied 14 percent of all Dutch foodstuffs, allowing local agricultural specialisation in high value dairying and fattening. Grain was primarily drawn from Poland, while the centre of the timber trade gradually shifted from the eastern Baltic to Norway, and the late 17th century saw the rise of a large German traffic, predominantly along the Rhine, but also the Elbe and Weser. Increasingly, large amounts of coal and grain were also shipped from England, supplementing the long-standing trade in wool and coarse woollen cloth. Small in volume but high in aggregate value was the trade in wood byproducts, carried via ports in the eastern Baltic, such as Danzig, Königsberg and Riga. This consumed vast quantities of wood by the standards of the age: the Dutch annually imported twice as much wood again, in the form of ash, as grew in the entirety of Britain, and at its peak ash consumed around 17 times as much wood as the Republic's timber imports. Finland was the main supplier of tar and pitch, essential components of the shipping industry, a trade again that outstripped the demand for actual timber (Warde, 2009). Nearly all these trades were conducted with regions where the wage levels were significantly below those in the western Netherlands and with low population densities, with the exception of its near neighbour, England (Allen, 2001; van Bochove, 2008).

The bulk trades that underpinned Dutch industry and shipping can be explained with recourse to the classic Heckscher-Ohlin thesis that areas trade goods according to their relative resource endowments. The land-poor but densely populated Netherlands specialised in manufacturing and services. Indeed, its one natural resource that was widely exported was fish, a specialisation that gets around the land constraint. In contrast, the grain fields of southern Poland or the great forests of Scandinavia, upland Germany, and the Baltic littoral and interior provided wood products; copper and iron came from Scandinavia, and lead from England. Indeed, much of these natural resource reserves, such as timber, were simply unused before Dutch demand drew them into international trading networks. This trade should be seen as a 'vent for surplus' from relatively remote regions that had little trading presence before the 17th century.

The trades were of course limited by transport and transactions costs; indeed one reason for the relatively slow entry of some regions into the international market was the lack of information and communication with northwest European demand. In the case of riverine transport, serious impediments, in the form of weirs, bridges and millworks, were only slowly removed by government interventions, creating an infrastructure for the timber trade. Everywhere, however, water was central to affordable transport: whether across the sea, Finnish lakes, or where grain and timber was borne down rivers from the hinterlands of Scandinavia, the Gulf of Finland, southern Baltic and Elbe, Weser and Rhine. Water transport was massively cheaper than that over land; in the case of bulk products, such as timber, well

over 90 percent of their final cost was composed of transportation charges. Hence accessibility was key to developing the bulk of trades, and the Netherlands was hugely advantaged by location. This was because of the multiple sources of supply. Although they shipped different kinds of grain, the Dutch could obtain the product from Poland (rye) or England (barley and malt); German timber could substitute Scandinavian or Baltic. This provided powerful downward pressure on commodity prices and the ability of suppliers to cream off rents. Similarly, some of the core products for industrial processes—such as the woodash alkalis used in textile bleaching, soapmaking, glassmaking and ceramics—had to be produced in remote areas, where rents were low enough (or negligible) to allow for massive consumption of wood, but also where the labour costs were extremely low. The highly refined products, as little as a thousandth of the weight of the initial inputs, could then bear the costs of transport (Warde, 2009; Radkau, 2007). The Netherlands was furthermore advantaged by the nature of its own geography, especially the westernmost and heavily industrialised province of Holland. Most Dutch commercial and industrial activity was packed into an area around the size of modern greater London, and much of this landscape could be easily traversed by lakes, rivers and canals. The early modern Dutch economy was almost an example of walking on water (de Vries and van der Woude, 1997).

The persistence of difference: Labour, capital and rents

One might expect that such an extensive range of interaction would eventually prove beneficial to the Netherlands' trading partners. Integration would lead to wage levelling and competitive pressures to specialisation. Dutch knowhow, technology and capital could become disseminated around northern Europe. High Dutch productivity would shift the terms of trade, thus 'exporting' some of the benefits of productivity gains to trading partners, through relatively higher prices for their goods. Yet this did not occur on a scale sufficient to shake the predominance of the core. Wages in Stockholm and Danzig were around 50-60 percent of the Dutch level after 1550, and after 1620 Polish wages suffered further relative decline. Neither did Norwegian or German wages show any catch-up before the 19th century. Growth in northern European economies was swallowed (literally, to a large degree!) by rapid population growth after 1750. In these circumstances, averting real wage decline was an achievement (Allen, 2001; van Bochove, 2008; Malanima, 2002).

In many of the peripheral regions, economic activity was dominated by the subsistence sector, and suppliers of natural resources made up only a small part of the labour market. In Norway, where timber generated 20-25 percent of export revenue, the industry probably employed no more than 3,000 workers out of a population of 600,000 (van Bochove, 2008). Work in many trades remained highly seasonal and tied to the agricultural economy. In the case of the grain and wood byproducts trades, many tens of thousands of workers must have been employed supplying the Dutch across swathes of eastern Europe. Nevertheless, their activity often represented only a part of their otherwise subsistence-orientated work; and many remained bound by feudal ties that limited the possibility of accumulation (Kula, 1976; Topolski, 1974). While the initial stages of potash or tar production were often undertaken by peasants, easy entry into the market probably kept returns depressed, and generally widespread and persistent underemployment probably explains some of the unresponsiveness of peripheral wage levels to core demand throughout the resource sector (Warde, 2009, van Bochove, 2008). Hence resource extraction proceeded under conditions of low labour productivity but equally low labour costs that did not create incentives for capital investment.

Resource extraction also did little to develop transferable skills. Flows of workers with expertise in copper-mining, sawmilling and mercantile activity tended to come from the Netherlands or central Europe, drawn by the high skill premiums and rents granted by monarchs eager to draw on their expertise. These ties were frequently essential for cementing commercial links and opening up sources of supply to Dutch markets, but after creating the initial 'vent' they did not produce an ongoing dynamic of development (Lindblad, 1982). In turn, the Dutch drew large numbers of unskilled workers into their own labour markets, undoubtedly thereby retaining international competitiveness for longer, and preventing actual population shrinkage, with high rates of Dutch male emigration to the colonies. In the first half of the 17th century some six to eight percent of the Dutch population had been born abroad, and in the province of Holland, this reached some 12-18 percent by 1650, where it may have accounted for half the male workforce. This made the Dutch economy more resistant to the labour shortage and upward real wage pressure that struck much of Europe as a result of demographic losses during the 17th century (van Lottum, 2008; Lucassen, 2000).

Neither did the primary products trade encourage significant amounts of capital or technological transfer, despite the fact that they could entail heavy capital investment. Wood-related trades tied up capital for very long periods of time, covering felling at the stump, initial processing, seasoning, transport from remote locations, auction and processing into retail products. Although the limited information on profit margins suggests that these could be similar across each stage of this process, in the case of imports from the eastern Baltic this inevitably meant much larger absolute returns to those who controlled the final stages of freight, from seaports or major transshipment centres on rivers such as Mannheim and Frankfurt— almost invariably Dutch merchants, with access to large reserves of domestic capital at low interest rates (Warde, 2009). Such merchants could also determine the moment of sale to maximise gains. Scope for producers to accumulate was thus limited, and capital accumulation was enjoyed by those who already had relative advantages in access to capital (cf. Krugman, 1981). The northern resource extractive industries and trades relied on complex multilateral trading arrangements, often finally settled by bills of exchange drawn on Amsterdam, which also retained a staple function for colonial wares and other consumer goods until the latter part of the 18th century. The profits and interest payments thus often returned westwards, even when regions ran a trade surplus with the Dutch. Frequently, however, the balance of trade ran in the Netherlands' favour (Lindblad, 1982; Pourchasse, 2006).

Conditions of underemployment, easy entry to the initial stages of extraction and low returns to labour that were squeezed down to the costs of extraction also limited the spread of technology. This does not appear to have resulted from problems with knowledge transfer. Wind-powered sawmills sporting multiple blades, for example, spread rapidly after an explosion in their use in the Netherlands in the 1590s. They could be found in Brittany by 1621, Sweden in 1635, Manhattan in 1623, and soon after Cochin, Batavia and Mauritius. Yet they were only widely adopted in Norway in the 1840s. Small-scale production, low wages and high interest rates all militated against the adoption of technology that had relatively high fixed costs (van Bochove, 2008). Technology was generally spread by migration of skilled craftsmen and engineers, and this does not appear to have been a concern for Dutch authorities before the 1750s.

Dutch advantage in finance may also have hindered indigenous development, though certainly not solely because of the weakness of indigenous institutions, but more probably their markets. Dutch capital was clearly an essential part of the Baltic and German trades, while both the Swedish and Danish-Norwegian

Crown made use of Dutch financiers. Crown debtors were able to obtain relatively favourable interest rates on Dutch markets (more favourable than private loanees) and the risk premium associated with lending to them does not appear to have been large. But the ease with which the Danish monarchs could raise credit in Amsterdam at low rates worked against the development of secondary bond and capital markets in Copenhagen. Frequently, repayment was fixed directly in the returns from extractive industries (such as copper mines) or the agricultural sector (van Bochove, 2008, Lindblad, 1982). Indeed, throughout northern and central Europe a standard procedure for rulers to extract rents from natural resources was to receive large loans from western merchants, who were repaid through licenses to extract resources, and who could do so in a highly destructive fashion (Mager, 1960; Warde, 2009). Nearly all the credits that went eastwards functioned as debt rather than equity instruments, which again removed the possibility of peripheral debtors profiting from the transaction (van Bochove, 2008).

But rulers did, of course, benefit from rents, as did the great feudal magnates of the east, who provided ash, tar, pitch and resin. But they did so at the least profitable stage of the supply chain, in a market with large numbers of suppliers and at times where the extractive process was difficult to monitor: hence an effective 'open-access' situation could prevail (see Barbier, 2005). These factors discouraged a careful harbouring of resources, and indeed created an incentive to exploit as far as was possible the use of unfree labour and feudal services, pushing capital costs in agriculture, for example, onto unfree tenants (Kula, 1976; Mager, 1960; Wallerstein, 1980). Those rents that were obtained were generally dissipated in political competition, and indeed in many cases were committed to military or court expenditure as soon, if not before, they came in. Resource extraction certainly did not create such institutional habits, and governments of the core were little different in their spending habits. But governments in the core existed in the context of more highly developed factor markets, where funded debt could facilitate, rather than hinder, capital investment. Resource extraction thus continued with low levels of labour productivity and with an expanding frontier towards more remote and less rentable districts.

Governments were not entirely inert in response to this. Legislation to regulate alleged deforestation, for example, was widespread, if weakly enforced and often amounting to rent-seeking on the part of the authorities (but most prominently in reserving expensive construction timber to the Crown). The Danish-Norwegian Crown set sawmilling quotas and restricted lumber exports in the 1680s to maintain price levels (Tveite, 1961). Similarly, the wood byproduct trade from the Swedish Crown was held as a monopoly by Stockholm. More strikingly, after 1724 Sweden followed a strongly mercantilist path of fostering import substitution through export quotas, targeted tariffs, a restrictive shipping policy that permitted countries only to ship their own (or their colonies') products into Swedish ports to break the Dutch staple, and easy credit for domestic producers. To some degree these measures achieved their aims, with the primary beneficiaries being the Swedish carrying trade and domestic textile production, although this increasingly relied on imported raw materials. But these protection measures could not alter the fact that the primary profits in the carrying trade and finishing processes utilising tar, pitch and iron were still obtained in the west. Production quotas must also have limited the already meagre upward pressure on producer wages (Lindblad, 1982; Müller, 2006). Both private and state-led sectors (to the degree to which they can be clearly distinguished) had limited opportunities, or indeed incentives, for capacity-building when the capacities that most pressingly mattered to the powerful were military prowess (at least the ability not to be overawed by neighbours) and successful commercial and financial linkages with the core. Sweden enjoyed a famously high literacy rate by early modern standards, without reaping the benefits until later in the 19th century.

The Netherlands thus demonstrated that growth was possible without a generous local resource endowment. But this was not a 'dematerialised' economy. A series of crucial linkages between the high productivity of their shipping sector, dominance in the carrying trade, the ability to obtain cheap raw materials, highly capitalised processing and manufacturing industries, high skill levels, and low interest rates consolidated and extended their advantage. Whether it was shipbuilding, linen bleaching, distilling, or armaments manufacture, the Dutch long enjoyed success, and thus the producers of timber, potash, flax, grain or copper were shunted towards further specialisation, with less scope for avoiding high marginal costs and thus persistently low productivity. It is hard to avoid focusing upon the extraordinary advantages of the location of the northern Netherlands, where its only abundant natural resource might be said to be the sea-lanes: drawing wool, tin and lead from the west; linens, timber and oxen from Germany; fish, copper, iron and wood products from Scandinavia; and wood, ash, hides and grain from the east. Equally, shipping dominance but a buoyant regional consumer market in the cities of the north-west compounded the advantages of economic density: factors that no supplier of raw materials could hope to emulate.

Indigenous energy resources and growth: British economic pre-eminence

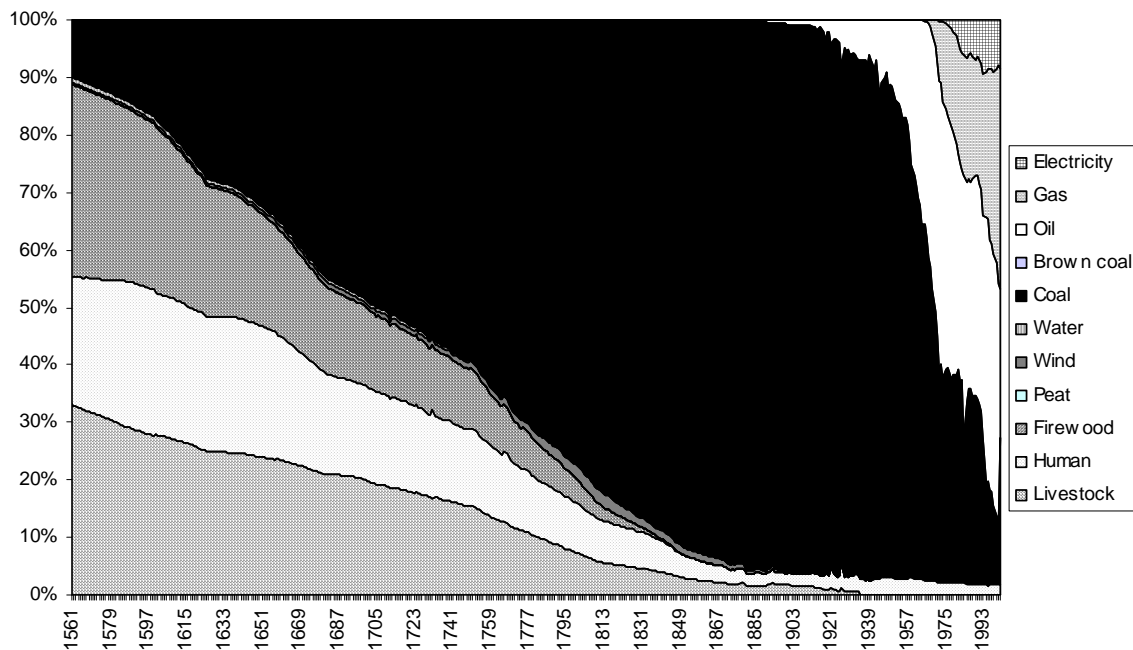
English development showed many of the characteristics that aided the 'Golden Age' economy of the Netherlands, and England too was heavily dependent on the import of naval stores, timber, ash and metals from the Baltic. These linkages spanned not just the northern seas, but the entire Atlantic world: every machete wielded by Jamaican slaves had been made in the great Swedish ironworks of Dannemora, at 60 degrees north (Evans and Rydén, 2007). The role of international, and especially colonial, trade in English development remains controversial (O'Brien, 1982; Pomeranz, 2000; Wrigley, 2006), and this paper will certainly not attempt to give a complete account of English economic growth. But English per capita income, probably not far behind Dutch by the late 17th century, surged ahead to reach new milestones before the end of the 18th: \$2,000 (1990 Geary-Khamis dollars (G-K\$)) before 1800 and \$3,000 by 1850, marked by an especially rapid acceleration in the middle of the 19th century (Warde and Lindmark, 2006). While the rate of English growth is now generally thought to have been slower and more incremental than in traditional narratives of 'Industrial Revolution', the levels achieved were nonetheless unprecedented (Crafts, 1985; Crafts and Harley, 1992). This income level was accompanied by unprecedented levels of energy consumption. 'Organic' economies outside the Scandinavian north do not seem to have been able to breach a ceiling of around 20 gigajoules (GJ) per capita being consumed each year. By the early 18th century, over half of the energy consumed in England was supplied by coal, and per capita annual consumption had reached 30 GJ. A century later, coal supplied over 75 percent of England's energy, and per capita consumption reached 50 GJ (Warde, 2007).

Coal and alternative energy supplies

Was growth without coal possible? The alternative supply of thermal energy was wood (sometimes processed into charcoal). Coal use had already outstripped wood use by around 1620, (see Figure 1), but this does not mean that wood supply could not have been sufficiently elastic if necessary. Whether the advance of coal was an 'induced innovation' caused by shortages of wood has been widely debated among historians (Hammersley, 1973; Flinn, 1959, 1978; Thomas, 1986; Hatcher, 1993; Allen, 2003).

For our purposes, it is not essential to answer the question of why a transition to coal occurred, but only what its economic consequences were. There are two price comparisons to be made, which allow us some sense of the elasticity of supply of possible fuel substitutes: between the prices of firewood and coal, and charcoal and coal. Charcoal rather than wood was required for heat-intensive processes, where the risk of chemical impurities also had to be minimised, such as in smelting and glassmaking. As more labour was involved in its production, its price was less sensitive to wood scarcity than the 'raw material', because a large proportion of the price was in the processing costs.

Figure 1: Energy carrier share in total consumption, England and Wales, 1560-2000

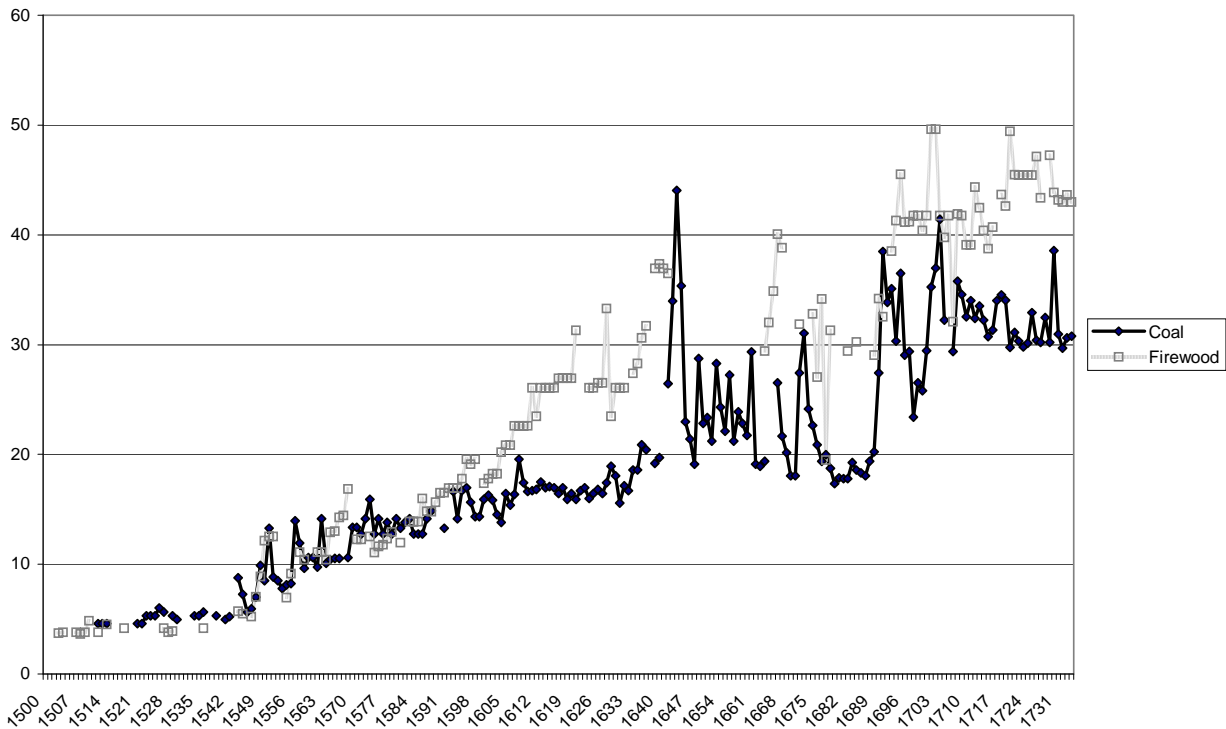


Source: Warde (2007)

In the southeast of England, wood prices diverged from coal prices from roughly 1570 until 1620, but afterwards their ratio remained quite stable (see Figure 2). Thermal energy from coal was cheaper to freight than wood (because of higher energy content by mass), but not than charcoal. Thus, any rise in capital and labour costs made wood disproportionately more expensive. Before 1570 coal and firewood cost roughly the same per British Thermal Unit (BTU) but firewood was much cheaper per ton, while by the 1620s both fuels were roughly equal in price per ton, but coal was less than half the price per BTU (cf. Hatcher, 1993). As getting the coal from pithead to a metropolitan consumer may have cost 80 percent of the retail price, the equalization of price per weight over time probably to a large degree represented an equalisation of the combined freight and rental costs for each fuel, given that extraction was largely performed by labourers with low capital costs, and wage rates would presumably not have widely diverged between miners and woodcutters. Coal supply was clearly elastic and the rents to be obtained per unit were low. As wood prices ran ahead of rises in wage rates until the middle of the 17th century, the firewood must either have been fetched from further afield or commanded a higher rent, or both: an indicator of rising relative scarcity. One pressure on wood prices from the 'organic economy' may also have been rising agricultural rents during the late 16th and early 17th centuries, both increasing the cost of the products of the land and creating a disincentive to invest in greater wood output (Allen, 1999). Wood prices in London rose by a factor of ten between 1530 and 1730, when the overall price

level rose by less than a factor of three, and wages by a factor of four, but the national wood supply remained almost static. London coal prices rose by around a factor of six in the same period, and coal supply rose by a factor of 18. Coal supplies were clearly highly price elastic and wood supplies highly inelastic. The price of charcoal, being sensitive to processing costs, was driven up particularly by wage increases in the 1640s.

Figure 2: Relative price of coal and firewood, London, 1560-1730



By 1800 Britain consumed around 15 million tons of coal, the equivalent of roughly 75 million cubic metres of wood. Domestic wood production was probably never much more than four million cubic metres per annum, and we have seen that domestic supply was highly inelastic, so a similarly energy-intensive wood economy would have had to import around 95 percent of its needs. Even were such vast quantities of wood available in near markets, a fleet many times the size of Britain's early 19th century merchant marine would have been required to transport this. One does not have to go far into the counterfactuals to recognise that Britain substituting wood for its globally exceptional level of coal consumption at any point in this period would be utterly implausible (Warde, 2007; for a less plausible view, see Clark & Jacks, 2007).

Energy and growth in industrialising Britain

England's per capita energy consumption was clearly unusually high: but was it essential for growth? Domestic hearths were the largest single consuming sector, accounting for nearly half the total in 1700, and still 35 percent in 1830 (Flinn, 1985). Clearly, the availability of coal made for much lower fuel costs

than would otherwise have been the case, but it is also true that this made domestic energy consumption, by western European standards, unusually high. Thus, while the relative cheapness of fuel

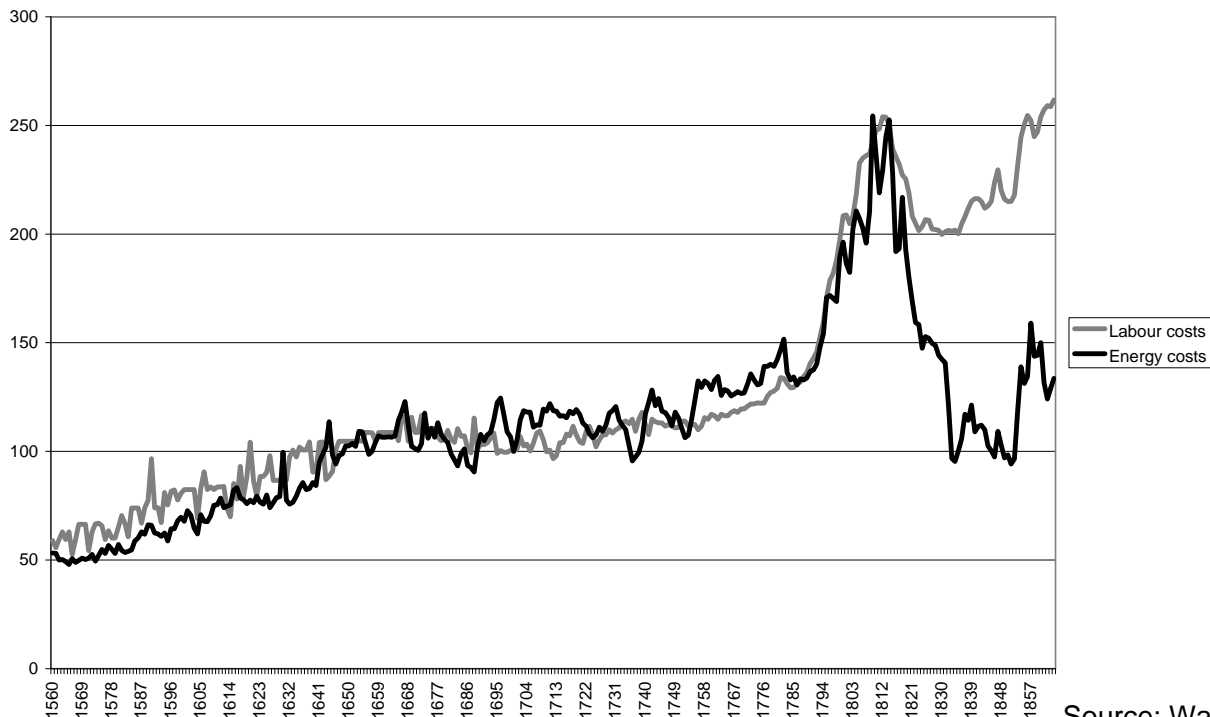
helped keep down wages for employers and boosted real income for consumers, it may primarily have contributed to greater comfort, although this in itself might have had other spillovers in consumption habits. Adam Smith commented in the 1770s that the location of the textile industries was driven by the availability of coal, because the long sedentary hours working indoors required higher levels of warmth than in households dominated by outdoor labour in agriculture (Smith, 1776).

Industrial consumption was distributed among many branches, and iron only became dominant during the 1820s (Flinn, 1985; Church, 1986). But unusually for the industrial sector, coal represented a natural resource with no opportunity cost: almost all other inputs were land based and thus competed with other land uses, increasing rent to the less dynamic agricultural sector. But the provision of energy itself is free, most notably in the form of fossil fuels: humans do not have to labour to produce it, but only to extract it, while in the case of capital and labour most of their cost is a payment for the reproduction of the factor. Because of the favourable proximity of coal reserves to the surface in England, this meant that a dramatic expansion in use could occur without dramatically pushing up marginal costs, and the benefits could accrue to the industrial and commercial sectors. In turn, this could lead to a dramatic expansion of energy-intensive industry in coal-producing areas, of which England had many, especially in the north and Midlands. But even widely distributed industries, such as lime-burning, brewing or brickmaking, could expand their operation greatly in one place.

Hence the early modern period saw a dramatic relocation of energy-intensive industry towards coalmining districts. The three centuries after 1600 also saw a huge redistribution of the national population towards the coal counties and London, which had become a coal-based city from an early date through imports from the northeast that occupied a very considerable proportion of the nation's merchant marine (Wrigley, 2008; Davis, 1962). Thus, coal could allow a dramatic expansion of glassmaking, copper and (primarily after 1780) iron production. These sectors by themselves may have contributed a fairly small share of national income growth, but growth in 'traditional' sectors, such as building or brewing, also made extensive use of cheap fuel. In turn, all of these brought multiplier effects in the largest sectors of agriculture and textiles. Iron was a key component of much equipment and capital investment and saw a 70 percent fall in price between 1770 and 1830, thanks to the development of the puddling and rolling process, at a time when prices of nearly all other industrial products, save cotton, grew (Crafts, 1985). After 1740, the domestic fuel demand occasioned by rapid population increase was almost entirely met by coal. Of course, fossil fuel was not the prime mover in all economic change, but it provided a centripetal force, which allowed Britain to benefit from indigenous consumption of its resources. The key advantages were threefold: firstly, extensive linkages between the resource sector and other dynamic sectors; secondly, the development of locality-specific skills, especially in smelting, that could only be transferred through relocation of the labour force itself (Evans and Ryden, 2007); and, thirdly, widespread spillovers.

Yet before 1830 this growth could only be incremental, because coal primarily provided thermal and not kinetic energy. In most parts of the country, energy was not cheap relative to wages, because most of the price of energy consisted of freight charges, which were largely reliant on the 'organic' economy and wind power. Unsurprisingly, the price of energy and labour moved closely in step over most of the land (see Figure 3).

Figure 3: Labour and energy prices, southern England, 1560-1860



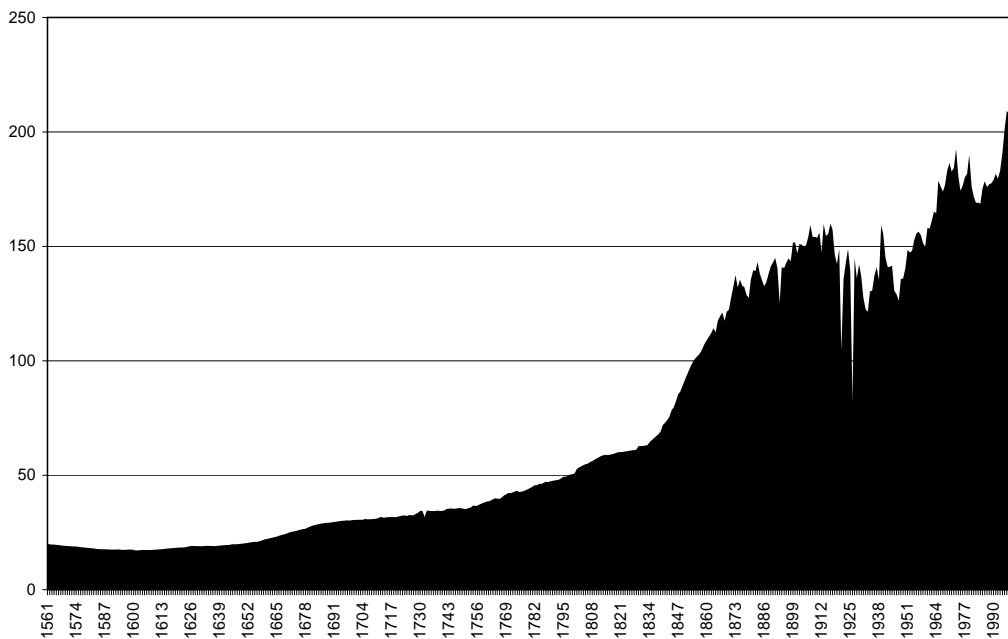
Source: Warde (2007)

Note: 1700=100, nominal prices.

The railways provided the essential breakthrough, at roughly the same time that the use of steam power became generalised in the textile industry. This caused an epoch-making plummet in the relative price of energy. Indeed, in nominal values, coal was no more expensive in the 1930s than it had been in the 1830s, and in real terms coal remains much cheaper than in the 1830s today. In fact, London coal prices did not return to their nominal 1800 level until 1947! It was thus in the middle decades of the 19th century that we see a step change in per capita energy consumption (see Figure 4), and also a take-off in wages in and GDP per capita (Warde, 2007).

This was an epochal shift, because it marked a long-term divergence of wage levels and energy costs that has led to persistent efforts to raise labour productivity over and above efficiency savings in energy use (although there have been plenty of the latter) (Warde, 2007; Fouquet, 2008). Energy-intensive sectors still only employed around ten percent of the workforce, but their multiplier effects were enormous. Lower transport costs did not encourage a dispersal of economic activity, as factor endowments and regional linkages remained operative. Cheap transport could, however, encourage the development of specialisation in non-energy-intensive sectors supplying industrial customers and each other—a shift given an international complexion by the development of steamships and bulk transport of agricultural products across the world's oceans from the 1860s.

Figure 4: Per capita energy consumption, England and Wales, 1560-2000 (GJ)



Source: Warde (2007)

The role of coal thus provided large gains for Britain across all sectors, not simply energy-intensive ones. Before the 1830s, the advantages of cheap coal brought a degree of industrial and population concentration, but enduring transport constraints did not lead to a resource-based export boom. Benefits accrued to the tradeable and non-tradeable sectors alike, and did not skew the pattern of investment. The real income gains from the railways and the enduring cheapness of coal certainly prompted large amounts of capital investment in industry and rapid productivity gains, which may match a phenomenon claimed for 20th century economies that energy services (i.e., the energy that actually does useful work) are highly complementary to capital stocks (Ayres and Warr 2003, 2006; Kander and Schön, 2007). Energy-intensive development effectively enjoyed increasing returns to scale, because of the ability to supply coal at ever greater quantities at no greater marginal cost, something difficult to achieve with most other inputs, although much of the output of energy-intensive industries was intermediary products, which required further processing or retailing. The shift in relative prices in favour of the non-tradeable sectors (before c.1870 being agriculture and services, which could not directly exploit cheap energy) attracted investment and meant that productivity rates also expanded and remained highly favourable until 1873 (Crafts, 1985). This helps explain why the returns to investment across the economy could remain relatively even, as coal use and the railways expanded, and refutes the argument that the 'normal' rate of return in railways or the coal industry indicated that they were not essential for growth, as capital could have been just as productively invested elsewhere (Fogel, 1964; Crafts, 2003). Such rates of return also occurred under conditions of highly elastic supply, with capital stock invested in railways shifting from zero (obviously) to 30 percent by 1855 (Matthews et al., 1982). Of course, one could argue that, given the essentially static or even slightly declining level of per capita income in pre-modern economies, simply the achievement of rates of growth that did not tend to diminishing marginal returns was itself a profound break with the past (van Zanden, 2004)

Conclusions

This paper has described the possibility of ‘two kinds of growth’ (Wrigley, 2004) and their relationship with natural resources. The Dutch case did not require a broadly-based natural resource endowment. Capital and skill made the Dutch more productive. Yet this capital and skill was developed in the context of a particular locational nexus, that gave them access to a wide variety of key resources at relatively low cost (albeit at much higher cost than the regions of supply). Location and the ‘endowment’ of a plenitude of water relative to land also promoted leadership in the carrying trade. Also essential to Dutch success was proximity to consumer markets. In contrast, regions of supply, while developing trade on the basis of relative resource endowments that encouraged the exploitation of wood, and other land-based and mineral resources, found in the Dutch a ‘vent for surplus’ that, however, left little room for the accumulation of rents, and that generally entailed low-skill employment with few, if any, spillovers into general development. The inherently long chains of supply and processing involved in the organic economy, that both tied up capital for extended periods of time and channelled supply through a limited numbers of sea- and riverine ports, also favoured those who initially had capital to invest. There can be little doubt that rents were dissipated by wasteful governmental expenditure and military adventure. Equally, suppliers of food and raw materials sought in the long term to maintain an adventitious place on the market, by using bonded labour and institutional rent-seeking, though this in itself reflects their inability to corner large rents by virtue of the resource endowment itself; the relative homogeneity of ‘organic’ economies means, in turn, that no one polity is likely to have exclusive control over a widely demanded good. But there is little evidence that the core-periphery trades of the early modern era generated backward institutions, or particularly expanded their capacity much beyond what they might otherwise have been. In the case of the relative success story of the Swedish bar iron industry, it is arguable that the coordinating efforts of the Crown, an output quota system, and the fortunate conjunction of two key resources (fuel and ore) meant that Sweden did not fall relatively further behind, unlike its eastern neighbours.

In contrast, England benefited strongly (but by no means solely) from its resource endowment. It was an essential characteristic of the burgeoning coal economy that it permitted ‘punctiform’ growth, with strong linkages and complementarities between sectors, including with the ‘organic’ economy in which it was for so long embedded. But this expansion could be built around some of the benefits also enjoyed (and to some degree derived from) the Dutch: relatively high skill levels, proximity to consumers, maritime location, and developed factor markets. But, clearly, transport constraints for a long time acted to restrict the degree to which these benefits could be generalised to allow for relatively rapid advances in income levels. The long view of British history suggests there has been a relatively close, if variable relationship between energy services (work done), capital formation and GDP. Before the 1880s this was primarily expressed through simply increasing energy inputs at declining levels of efficiency, but with a highly elastic supply of coal. The modern era of growth—which post-dates the appearance of the railways—was more capital-intensive, and from the 1880s has been increasingly energy efficient. This last fact has disguised the fact that it has been accompanied by a relatively consistent ratio of energy services to capital and GDP, at least until the 1970s (Warde, 2007; Ayres and Warr, 2003, 2006; Kander and Schön, 2007).

Natural resource dependency is not necessarily a boon, but nor is it a curse. The character of development, and its relation with resources, is seen in these historical cases to relate closely to the ability to control circuits of capital, employ location-specific skills, and access to consumer markets.

Whilst institutions may shape these factors, in the long term it also appears that 'good' institutions do not by themselves cause either success or failure; and 'bad' institutions may well reflect the weakness of the resource-exporting economy, rather than being the cause, via rent-seeking by elite groups and a neglect of the local tradeable sector, of relative backwardness. The availability of substitutes on international markets depressed prices and rents. In other words, the Golden Age Dutch did not export the 'Dutch disease', but neither did they export a Dutch cure. The northern Netherlands was, under particularly favourable circumstances, able to take economic leadership, despite a heavy dependency on imports for nearly all natural resources excepting fuel (though even here coal imports became significant) and on the sea that brought resources to their doorstep. On the other hand, whilst the discussion of English growth presented here is necessarily very partial, and while that economy displayed some of the characteristics of its near neighbour, native energy reserves seem to have been a key aspect of its success. Crucial here was the escape from dependency on organic resources, and the lack of competition with other land uses (and hence low opportunity costs). If the resource base of the future is going to shift back towards land-intensive uses (such as biofuels, with attendant demands on water, as well as competition for space and fertiliser), such historical examples may give us pause for thought. Equally, if the environmental costs of energy-intensive fossil fuel-based development, and its characteristically low transport costs, have been a key aspect of modern growth, is it possible to imagine a world where transport becomes again a relatively more expensive enterprise? One might expect older patterns of trade and relative fortunes to reassert themselves, with an attendant pattern of beneficiaries and 'backwardness'.

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