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SESSION 49 - Energy and Growth in the Long-run

Changing Energy Regimes and Early Modern Economic Growth

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It is a commonplace of economic history that the Industrial Revolution was based on increased use of coal. The view is a standard and well established one. The description is straightforward. The shift away from various energy carriers that relied on continuing doses of solar energy to inorganic sources which had stored up solar energy made for modern economic growth. England was *The First Industrial Nation*[1] and set the pattern for the rest of the world not only in rising output and rising per capita income but also in energy use and specifically coal use. An unfortunate side effect of that observation, no matter its accuracy, is a tendency to equate greater energy use from non-muscle power with a successful economy and therefore to attribute economic growth to supplies of fossil fuels. In that scenario getting away from solar power is not only a way but is largely the way to create a modern economy. Stating matters so baldly, it is true, does not do justice to measured assessments of the roots of economic growth. It

[1] P. Mathias, *The first industrial nation : an economic history of Britain, 1700-1914*. 2nd ed. London ; New York : Methuen, 1983.

also ignores the exploration of various alternative explanations in recent years.[2] That said the idea that changing energy regimes was essential to growth have been generalized both to the years after 1800 in Britain and pushed back before the Industrial Revolution into early modern Europe. The most notable and justifiably influential case is the Netherlands where Jan DeVries and Ad van der Woude, in their magisterial summation of generations of research on the economy of the early modern northern Low Countries, argued that virtually all the features of modern economic growth evident since the Industrial Revolution were to be found in the region in the seventeenth century. Among the features they pointed to was the role of peat, acting much like coal in England two centuries later, providing A...a uniquely large supply of heat energy...@ which helped to explain the concentration of industry and the success of Dutch industries in export markets.[3]

Certainly for them inorganic fuel sources were an explanation and possibly a critical explanation for modern economic growth.

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[2] For example, E. A. Wrigley,"Introduction: What Was the Industrial Revolution?" In *People, Cities and Wealth The Transformation of Traditional Society*, Oxford: Basil Blackwell, 1987, 12; R. C. Allen, AProgress and poverty in early modern Europe,@ *Economic History Review*, 56 (2003), 403-443.

[3] J. DeVries and A. van der Woude. *The First Modern Economy: Success, Failure, and Perseverance of the Dutch Economy, 1500-1815*. Cambridge: Cambridge University Press,

1997, 338-339, 694, 709-710.

To assess the general argument that new sources of energy were a major, if not the major, contributor to expansion of the economy from about 1550 to about 1800 it seems prudent to concentrate on the two economies which enjoyed the fastest growth in the period, and that is growth in both gross output and per capita output. They both were in northwestern Europe on either side of the North Sea: the northern Netherlands which from 1581 was even if reluctantly the Dutch Republic, and England which included Wales and, thanks to Acts of Union in 1709, included Scotland in the kingdom of Great Britain. To make a first and very general appraisal of the role of coal and other fossil fuels in the early modern economy three closely related and interconnected questions deserve immediate attention. The first is to ask whether energy use increased in those polities through the period about 1550 to about 1800. That is strictly an accounting problem but there are serious difficulties with counting not only how much energy might have been used but in comparing the relative contributions of different energy carriers to the total. The second is to ask what the sources of energy were, that is what was the energy regime and whether in fact in the period it changed to one dominated by fossil fuels, in the case of the Netherlands to peat and in the case of Britain to coal. In trying to assess the contribution of the different carriers results point more to gaps in knowledge than supply firm conclusions. Those gaps have been created over the last century and more of research into the early modern economy in part by presumptions about the roots of growth and the critical role of fossil fuels. Modern energy crises have helped to concentrate interest on past heavy reliance on one energy carrier. The perceived importance of fossil fuels in the nineteenth century and before has generated a concentration of study on exactly those fuels at the expense of alternatives. The third is to ask what the contribution of energy was to economic growth or more precisely what

was the contribution to non-agricultural activities of changes in energy use that both in gross terms and relatively among the energy carriers. By implication the issue is a rather general one: to what degree did increased inorganic energy use create an Industrial Revolution or the signs of one in early modern Britain and the Netherlands.

All efforts to establish total energy use in the Netherlands and Britain as with anywhere else in early modern Europe very quickly fall victim to problems of counting. Data comes from both production and consumption. While prices for some carriers may be available they do not necessarily indicate anything about levels of energy use. Coal in England, for example, was in virtually infinitely elastic supply through the seventeenth and eighteenth centuries. Any rise in demand elicited an equal response in supply so prices remained stable.[4] There are no global data on energy consumption, as there are no such data for any later period. To get an overall figure it is necessary to estimate energy use for each separate energy carrier. Doing calculations for each one makes the task more difficult and does little if anything to decrease the already significant range of error. Examining total energy use becomes at the outset an effort to estimate the distribution of energy used among the various carriers.

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[4] J. Hatcher, *The History of the British Coal Industry*. Vol. I Before 1700: Towards the Age of Coal. Oxford: Clarendon Press, 1993, 95.

Historians have debated the scale of energy supplies in the pre modern Netherlands since the appearance of an article at about the time of the second energy crisis of the 1970s. J. W. De Zeeuw in his >Peat and the Dutch Golden Age: The Historical Meaning of Energy-Attainability,= concentrated on peat production. He based his estimates on the land area dug through the seventeenth and eighteenth centuries. Since then J. L. Van Zanden, M. A. W. Gerding, and I, and very soon C. L. E. Cornelisse, have joined in with calculations, in some cases supporting De Zeeuw=s position and in others attacking it. As things stand it appears that De Zeeuw was too optimistic and some of his critics were too pessimistic about total Dutch peat supplies.[5] Differences turn on questions of total production and even more on the amount of energy a unit of peat could produce, a figure heavily dependent on the moisture content of the peat and so heavily dependent on immediate conditions (See Table 1).

While debate has turned on the amount of energy from peat quantities from firewood have been largely ignored. The assumption that a flat and treeless country would have had no wood for heating and imported wood solely for building is certainly incorrect. Not only were

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[5] J.W. De Zeeuw, >Peat and the Dutch Golden Age: The Historical Meaning of Energy-Attainability,= in: *A.A.G. [Afdeling Agrarische Geschiedenis, Landbouwhogeschool Wageningen] Bijdragen* 21 (1978), 3B31; R. W. Unger, >Energy Sources for the Dutch Golden Age: Peat, Wind, and Coal,= in: P. Uselding (ed.), *Research in Economic History* (Greenwich 1984) 221B253; M.A.W. Gerding, *Vier eeuwen turfwinning : de verveningen in Groningen, Friesland, Drenthe en Overijssel tussen 1550 en 1950*, Utrecht : HES, 1995; J.L. van Zanden, >Werd de Gouden Eeuw uit turf geboren? Over het energiegebruik in de Republiek in de zeventiende en achttiende eeuw=, in: *Tijdschrift voor Geschiedenis* 110 (1997) 484-499; M. A. W. Gerding, "Wie van de drie? Wil de echte acrobaat opstaan?" *Tijdschrift voor Geschiedenis* 111 (1998): 95-100; C. L. E. Cornelisse, AThe economy of peat and its environmental consequences in Holland during the late Middle Ages,@ *Jaarboek voor Ecologische Geschiedenis*, forthcoming.

there managed woodlands in the western provinces of the Netherlands but also wood for burning was brought from regions just to the east of Holland. While there are few figures for wood used to generate heat certainly there was a market for firewood in Holland. The principal limitation on the scope of wood distribution and the markets where it was sold was, even more so than with fossil fuels, transport costs. In certain places and for certain periods of time firewood could do well in competition with peat and, on the other hand, for some periods peat was overwhelmingly the choice for heating fuel. Given the segmented nature of the firewood market and the fluctuations in supply it is possible to say little more than that wood made a contribution and a continuing contribution to total energy use, that up until about 1750 when the close connection between the peat and firewood markets suggests wood production had reached its maximum.[6]

[6] J. Buis. *Historia Forestis Nederlandse bosgeschiedenis*. 2 vols, *A. A. G. Bijdragen 27*. Wageningen: Afdeling Agrarische Geschiednis, Landbouwhogeschool, 1985, 487-493.

The Dutch countryside was marked by a profusion of windmills, mostly there from their introduction for pumping water in the fifteenth century to drain the land. But there were also many mills devoted to industrial production and not just in the Zaanstreek north and west of Amsterdam, a region renowned for the number of mills. According to one survey in 1630 there were 128 mills there doing everything from making paper to crushing sand. By 1731 the number was up to 584 and in 1795 it had fallen back to 482.[7] Using De Zeeuw=s generous estimate of the energy produced by a windmill at 2.5 kilowatts and his generous estimate of 3000 windmills working 24 hours per day 300 days per year that puts the figure for total energy derived from wind powered mills in around 1650 in the Dutch Republic at 45 billion kilocalories in around 1650.[8] Though the number of industrial mills probably fell in the eighteenth century the efficiency of mills increased so the figure for the mid seventeenth century is probably not far off

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[7] J. DeVries and A. van der Woude. *The First Modern Economy: Success, Failure, and Perseverance of the Dutch Economy, 1500-1815*. Cambridge: Cambridge University Press, 1997, 346-347.

[8] R. W. Unger, >Energy Sources for the Dutch Golden Age: Peat, Wind, and Coal,= 228-229.

for the mid eighteenth. The totals are small, however, compared to energy that came from burning peat.

Another source of thermal energy, in addition to firewood and peat, was coal. The tendency has been to ignore or understate the contribution of coal to the Dutch economy, the reasons perhaps having to do with a reluctance to acknowledge that the Dutch Republic relied on foreign suppliers for that source of fuel. The coal came downstream from Liège or across the sea from the northeast of England. Figures for imports from the southern Low Countries are certainly difficult to find, especially since some of the coal that came in was then reexported through Dutch ports. My own estimates of net imports of 25,000 tons around 1650 and 75,000 tons around 1750, rising to 100,000 tons by 1800 may well be too high but, even reduced, the number suggests an impact on the general energy regime. Even more impressive were coal imports from Britain. Data for those shipments are slightly more reliable since the English government levied taxes on exports with prohibitive duties levied if the coal went out in foreign bottoms. The coal was all carried in English ships but that did not guarantee that all exports were reported to the tax collector. David Ormrod has recently and conclusively shown that tax evasion by English captains from around 1710 to 1749 has led to underestimation of the quantity of coal that went to the Netherlands (See Figure 1). The higher levels he finds confirms extensive use of coal in Holland, presumably largely in industry. It was the preferred fuel for metal working and also found a place in producing beer but may well have enjoyed even broader industrial and domestic applications if consumption levels were that high. English coal shipments to Holland were in the 30,000 ton per year range in the seventeenth century and about 100,000 tons per year by the mid eighteenth. Scottish imports added some 10,000 tons per year

to the total on average in the mid seventeenth century about 40,000 tons by the end of the eighteenth.[9] Coal use was considerably higher in the mid eighteenth century than in the mid seventeenth though it was still significant in the >golden century=. The estimate for the earlier date is confused by imports from Scotland which was not as carefully recorded or taxed by the authorities north of the Tweed as were imports from England. In addition therre are serious problems with measuring the scale of imports into the Republic from the southern Netherlands.

The higher contribution of coal than is generally acknowledged combined with the large scale use of peat and the growing number of windmills combine to suggest a long term increase in total energy consumption in the Dutch Republic possibly to the 1750s. Since the population of the western provinces was more or less stable after the boom of the first half of the seventeenth century that meant that per capita energy consumption must have risen as well and at more or less the same pace as the increase in total energy consumption. The matter hinges on the estimate of calories derived from a unit of peat. De Zeeuw=s generous approximation places the peak of energy consumption in the seventeenth century followed by a decline. Using my lower bound estimate for energy use there appears to have been a sustained overall rise in the

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[9] D. Ormrod, *The Rise of Commercial Empires England and the Netherlands in the Age of Mercantilism, 1650-1770, Cambridge Studies in Modern Economic History*. Cambridge: Cambridge University Press, 2003, 252-262; R. W. Unger, >Energy Sources for the Dutch Golden Age: Peat, Wind, and Coal,= 239, 246.

eighteenth century. Van Zanden=s figures, on the other hand, suggest a decline in the eighteenth century and especially in the second half.

For England, and rather Britain after 1707, there is a long standing debate about the exhaustion of wood supplies in the seventeenth century. The debate began among contemporaries and it seems unlikely to end, though there are signs of a resolution of conflicting views. The belief that since English, and for that matter European, forests were reaching the limits of their capacity to supply firewood people shifted to fossil fuels and so generated long term economic growth is one which has enjoyed currency for some time.[10] While that position has had opponents it has also gained supporters, the divisions being based on whether or not to believe contemporary Cassandras, whether or not to trust data on consumption levels for various industrial purposes, and whether reliable figures exist for English firewood output.[11] Recent efforts suggest claims of dire shortage in seventeenth century England are unsubstantiated. Firewood production it appears probably peaked in England not until the middle of the eighteenth century. Proper management of woodlands meant that output could still increase,

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[10] Richard G. Wilkinson, *Poverty and Progress An ecological model of economic development*. London: Mathuen and Co Ltd, 1973, 112-123; J. U. Nef, *The Rise of the British Coal Industry*, London: Routledge, 1932 [reprinted London, 1966]; R. P. Sieferle, *The Subterranean Forest Energy Systems and the Industrial Revolution*, Michael Osmann, trans., Cambridge: The White Horse Press, 2001. Original German edition published as *Der unterirdische Wald*, Munich: C. H. Beck, 1982.

[11] E. g. G. Hammersley, AThe Charcoal Iron Industry and its Fuel, 1540-1750,@ Economic History Review, xxvi (1973), 593-61; B. Thomas, AWas There an Energy Crisis in Great Britain in the 17th Century,@ *Explorations in Economic History*, 23 (1986); 124-152; R. C. Allen,@Was There a Timber Crisis in Early Modern Europe?@, *Economia e energia secc. Xiii-xviii, Serie 'II-Atti delle "Settimane di Studi" e altri Convegni*, 34, Instituto Internazionale di Storia Economica "F. Datini", Prato, 2003, pp. 469-482.

admittedly at a low rate, until the eve of the Industrial Revolution. So English wood supplies were not exhausted in the reign of Elizabeth or even under the Stuarts. Whatever sense of urgency there was about wood supplies had much more to do with the changing structure of demand than with how much firewood was being cut.[12] The contribution of wood to total energy then did not rise after around 1750 and did not rise much through the seventeenth and first half of the eighteenth century. So for England if there was growth in energy use it came from other carriers. The supply of one carrier did rise and rose dramatically and almost continuously, and that carrier was coal.

[12] P. Warde, personal communication, 1 May, 2006; Ben Gales, Magnus Lindmark, and P. Warde, ATraditional energy carriers and growth,@ XIV International Economic History Congress - Helsinki, SESSION 49 - Energy and Growth in the Long-run.

Figures for coal production and consumption are extensive, reliable and well known (See Table 2).[13] They show a long term rise in output, most notably for the years up to 1800, in output from mines in the Northeast and for shipment of coal dug there through the ports first of Newcastle-upon-Tyne and later of Sunderland. Annual exports of around 200,000 tons in 1600 rose by 1700 to close to 700,000 tons and the pace of growth in the eighteenth century was even faster, helped not incidentally by exports to the northern Low Countries (See Figure 2). Shipments to Holland reached 35,000 tons by 1700 and almost 120,000 tons by 1745. But by that later date colliers were landing about more than 600,000 tons alone at London, almost all of that coming from northeast ports. Total English coal output was some 5,230,000 tons in 1750 but was to triple that figure by 1800 and double the 1800 figure by 1830 (See Figure 3). It was a far cry from around 1550 when the northeast ports shipped 14-16,000 tons of coal each year or around 1610 when they sent out about 150,000 tons each year or 1640 when quantities had gotten up to 300,000 tons.[14] In 1610 coal sent from northeast ports had an energy value of about 112 trillion kilocalories while the total amount of energy that came from Dutch peat bogs was 1,750 trillion. By 1640 the Dutch peat figure was as high as 6,000 trillion though probably considerably less than that while the English coal figure was up to 2,250 trillion. The gap narrowed or may have been all but wiped out by the mid seventeenth century. While shipments

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[13] See J. U. Nef, *The Rise of the British Coal Industry*; J. Hatcher, *The History of the British Coal Industry*: M. W. Flinn, *The History of the British Coal Industry*. Vol. 2 1700-1830: The Industrial Revolution. Oxford: Clarendon Press, 1984.
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[14] J. Hatcher, *The History of the British Coal Industry*, 41; David Ormrod, *The Rise of Commercial Empires*, 252-254; M. W. Flinn, *The History of the British Coal Industry*, 26.

from Newcastle and Sunderland were only a portion of total English production they were a significant and perhaps even rising share. Large and unmeasured quantities of coal were produced throughout the country at various sites. That coal did not enter trade, was used locally, and so did not find its way into official or national records. The same was true of peat production which, in some parts of England and Scotland, was locally significant.

The high levels of and the sustained increases in coal output have obscured the existence of windmills and watermills which also produced energy even if of lesser and declining importance to the total for the economy. Windmills in East Anglia alone may have exceeded the number in the Dutch Republic in the seventeenth century, in part because of the need to drain land that was under sea level and in part because of an expanding cloth industry which needed sources of power. In 1820 there were about 5,000 windmills in Britain though it is possible the number was as high as 10,000. The figure appears to have doubled between 1760 and the 1820s, though power from windmills had by the latter date fallen to 6% of total energy use and that share was perhaps half of what it was in 1760.[15] The indication then is for a sustained increase in the amount of energy that came from windmills but a fall in the share of energy that came from wind, any growth in the absolute amount being swamped by the increase in coal as an energy source. Taking De Zeeuw=s estimate for the efficiency of windmills used for the Netherlands then in the mid eighteenth century people in Britain were getting some 45 billion kilocalories per year from windmills, a figure that rose to perhaps 90 billion kilocalories by

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[15] R. L. Hills, *Power from wind A History of windmill technology*. Cambridge: Cambridge University Press, 1994, 75, 78.

around 1825. It is not possible, at least at this stage to make a similar estimate for watermills though it is all but certain that the number was larger and the energy output greater. Watermills increased in size and efficiency if for no other reason that they got larger. It is likely that their numbers increased though it is hard to believe, though likely, that the total was greater than the medieval maximum of from 12-15,000 of about 1300.[16] Watermills were the standard sources of power in cotton and woolen mills up to 1820s and 1830s when they were replaced in many places but not everywhere by steam engines. Indeed the Industrial Revolution in its early stages promoted the use of water power. Some manufacturers even bought steam engines to pump water already used to power wheels back up into their mill ponds for recycling.

There can be no doubt that overall energy use in rose England between 1550 and 1800 and rose significantly. England already had high energy use levels in 1600 so the gains made on top of those meant that people in Britain consumed more energy - much of it thermal energy - than people anywhere in Europe, with the possible exception of the northern Netherlands and people in the northeastern part of the Continent where the climate forced massive consumption of heating fuel. It also meant that Britons and probably for a long time, were among the most voracious users of energy of any other people in the world in the early modern period and into the nineteenth century. The rise in coal consumption meant that in percentage and in absolute terms energy consumption rose, that is even without more firewood and rising numbers of windmills and watermills. British population grew in the period and, after something of a lax

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[16] A. R. Lucas, Machinariarum nihil ex Deo: *the role of the church in the development of powered milling in high medieval England.* Unpublished Doctoral Dissertation, University of New South Wales, 2003, 5.

period in the late seventeenth century, dramatically most notably after about 1750. Energy production rose even faster, however, so that despite the greater numbers of people energy use per capita in 1800 was higher than ever before.

The distribution of energy carriers among the varied sources is obvious from the examination of energy production. It was fossil fuel use which rose most dramatically in the two economies in the seventeenth and in Britain even more in the eighteenth century. The concentration on that increase in peat and more important on coal output, however, ignores or underestimates other sources of energy, a number of which also grew. Wind power in England is one obvious case. Similarly coal use in the Dutch Republic has received less attention than data suggest it should because the Netherlands is a place where peat predominated.

Paul Warde argues that coal began to contribute a larger share to total energy consumption than firewood in England already in around 1587.[17] The date seems very early given the potentially sizeable firewood use in the sixteenth century, use which appears to have continued at similar levels for a couple of centuries. Peat on the other hand probably superceded firewood as an energy source in the Netherlands even before 1587. It is at least possible to say that the two economies were the first in Europe to rely more on fossil fuels than on firewood for thermal energy. Taking not total use but per capita use the much smaller population of Holland got more energy from peat and coal than did their English counterparts from coal. That is the case even accpting my low estimate for Dutch peat energy output (See Table 3). If firewood were added to the quantity from coal then the English would emerge as greater energy

[17] P. Warde, personal communication, 1 May, 2006.

consumers. By 1700 just counting fossil fuels England had forged ahead of the Dutch Republic. Even if the Low Countries lagged behind the relative contribution of fossil fuels continued to rise in Britain and for most of the period in the Netherlands from the second half of the sixteenth century. Though the proportion rose and became dominant that did not mean that other carriers disappeared or were of no importance to the Dutch or British economies. If for example windmills in the Dutch Republic supplied 4% of total energy in around 1650 or if in England they supplied 12% of energy in 1760 that overall and not just at the margin could have been significant to people in the two jurisdictions. The confidence in any estimates of fossil fuel use must be slim, based as they are on inaccurate measures which are based on different kinds of sources and different methods to create them. A more critical figure and one which might be of greater value in assessing the role of fossil fuel consumption in economic growth is the contribution of the various sources per capita to industry and commerce.

Energy carriers were not created equal when it came to conversion of latent energy to work. Existing technology as well as investment in devices to exploit the energy deeply affected how much of a difference the energy made to production. Even animals and humans were more effective than efficient stoves of the eighteenth century in getting work out of energy supplies (See Table 4). And in the eighteenth century efficient stoves were not in common use, or at least apparently not in England. Since much of the energy of fossil fuels dissipated on burning the total available to do work was a small share of the total energy in the peat or coal. In addition a significant portion of all energy was not used in industry. The principal alternative was in home heating. An adjustment for the proportion of peat and coal energy actually used in industry further reduces the contribution of that rising quantity of energy to industry and commerce.

In the Netherlands more peat found its way into industry than did coal in England. Something on the order of 58-67% was the industrial part of the energy figure in the mid sixteenth century and there is little reason to believe the share was less through the seventeenth.[18] In England only some 40% of coal went to industrial uses in the seventeenth and first half of the eighteenth century. Even with the proportions higher in Holland than in England and taking into account efficiency of burning, Dutch industry showed more energy use per capita in the mid seventeenth century but less in the eighteenth and by an increasing margin(See Table 5). Taking into account both efficiency and the share of peat burned for industrial purposes wind power takes on greater importance for the economy. Considering both factors per person the contribution of windmills in the Netherlands was anywhere from 0.9% to 5.6% of that of peat (See Table 6). Overall Dutch energy use per capita was lower than in England. In the seventeenth century a combination of firewood and coal made English levels higher but in the eighteenth century coal use alone was enough for English energy users to outdistance the Dutch. Despite the differential the Dutch enjoyed higher incomes per head through the seventeenth and even through the eighteenth century. It was only in the second or third decade of the nineteenth century that people in Britain finally enjoyed an income level comparable to that of the Dutch. The Dutch were able to maintain their superior position despite the fact that they used significantly less energy per person per year than their British counterparts by the eighteenth century. Whether energy use in total and per capita continued to rise in the Republic through the eighteenth century is open to question. Even so in a period when the economy was stagnant and

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[18] C. L. E. Cornelisse, AThe economy of peat and its environmental consequences in Holland during the late Middle Ages,@ 5 in ms.

per capita income remained more or less constant Dutch consumers kept their energy consumption more or less the same or decreased it by some estimates, indicating incidentally that the effective contribution to industrial production went down. Using lower bound estimates for Dutch energy use something on the order of an 18% increase in energy use between 1650 and 1750 led to a nil increase in production. The Dutch economy become less energy efficient. Using De Zeeuw=s figures in conjunction with those of van Zanden the opposite was the case with a 40% drop in energy consumption in a century and a half to 1800 yielding no loss in output. That high number is another reason to question the accuracy of De Zeeuw=s guess. A fall in energy use is, however, consistent with the pattern in other Amodern@ economies where the tendency has been for energy use per unit of output to go down as the economy becomes more mature - the so-called Kuznets energy effect. The same might have happened in the Dutch economy since there was a shift, as observed with many developed economies in the late twentieth century, from industry to services. The financial sector, for example, became relatively more important in Holland while certain industries, most notably the energy gorging brewing industry, declined.[19] The expectation would be, based on both theory and experience elsewhere, for energy use absolutely and per capita to have gone down rather than up. That was possibly the case. One implication from the ambiguous results is that analogies of the early modern Dutch economy with advanced economies after the Industrial Revolution should not be

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[19] R. W. Unger, *A History of Brewing in Holland 900-1900 Economy, Technology and the State,* Leiden: Brill Academic Publishers, 2001, chapters 7, 14.

pressed too strongly.

In England the share of total energy consumed devoted to industrial production was significantly lower than in the Netherlands. The English and Britains in general, including Scots and Irish, preferred to devote the large quantities of energy produced from their mines and peat bogs to home heating. The total share of energy that went into domestic hearths was always large. In 1700 nearly half of all coal was used domestically, that is for cooking or heating. As late as 1800 the proportion had only fallen to some 35%. Per capita coal consumption for domestic use rose until the 1770s and only then leveled off (See Figure 4). It took a long time before people in Britain felt warm enough at home. Since domestic use of coal was so significant then the rise in energy use has to be related to how the coal was burned. With coal easily available then the barrier to increased use was having a place where firing would have been moderately effective. Coal could not burn efficiently in large open fireplaces like those of grand Renaissance halls. It needed small, confined spaces and grates to keep the fire burning. It was the shift in fireplace construction, the gradual adoption of different facilities for burning which especially in the seventeenth and but also in the eighteenth century which John Hatcher among others has offered as an explanation for the rise in fossil fuel consumption in England.[20] While the claim that just changing fireplaces was why English coal output went up and while such claims ignore the presence of stoves, already built in the high Middle Ages and in widespread use on the Continent in the sixteenth century, still there are some reasons to believe

[20] J. Hatcher, *The History of the British Coal Industry*, 409-418.

that changes in domestic architecture did effect energy use. First, the high proportion of coal used in home heating meant that more places to burn coal would automatically increase demand. Second, there are signs of changes in domestic architecture toward smaller fireplaces. The most obvious change was moving mantles lower on walls and the resulting appearance of portraits and mirrors over the fireplaces, something noticed in France in the second half of the eighteenth century.[21] Third, after the Great Fire of London in September, 1666, the government imposed regulations for the rebuilding which favoured more substantial houses. If in fact the trend was toward fireplaces that were more suited to using coal then logically as the new houses were built the quantity of coal imported into London should have increased. The government, however, in order to pay for public works associated with the rebuilding, imposed a duty on coal which was especially onerous in its first dozen years.[22] That presumably deterred a shift to using coal temporarily and from about 1680 the expectation would be for a rise in London coal use. In fact that does appear to have happened (See Figure 5). So even if assertions about the design of fireplaces determining fossil fuel consumption seem preposterous at first blush, there is considerable evidence including that of London after the Great Fire which suggests that there is something in such contentions. If the claims are true, though, they serve to erode arguments

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[21] A. Pardailhé-Galabrun. *The Birth of Intimacy Privacy and Domestic Life in Early Modern Paris*. Translated by Jocelyn Phelps. Cambridge: Polity Press, 1991, 118-120.

[22] T. F. Reddaway. *The Rebuilding of London after the Great Fire*. London:

which connect economic growth to rising energy consumption. Greater coal output was keeping English rooms warm, not contributing directly to more output.

Edward Arnold & Co., 1940, 85, 123, 181-187..

Not incidentally London as a centre of consumption of coal was seen as a driving force in boosting demand and, therefore, production of coal. The industrial expansion of the late sixteenth and early seventeenth century was connected to the expansion of London and of industry there.[23] It is certainly true that London grew in population and remarkably from the sixteenth through the nineteenth and even twentieth century. It is true that London was the major destination for a large and, in the seventeenth century, growing share of northeast coal output. It is true that the coastal trade in coal made a considerable contribution to total English shipping. However the coal that went to London apparently went there largely for home heating. In that London was no different from the rest of England. London had significantly higher levels of coal consumption per capita in the seventeenth century but by 1750 the rest of Britain had caught up and by the start of the nineteenth the capital was well behind levels in the rest of the country (See Table 7). In London as elsewhere it was apparently not just industry and industrial uses that made for greater reliance on fossil fuels but rather choices for domestic

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[23] J. Hatcher. "The Emergence of a Mineral-Based Energy Economy in England, c.1550-c.1850." In *Economia e Energia Secc. XIII-XVIII Atti della "Trentaquattresima Settimana di Studi 15-19 aprile 2002*, edited by Simonetta Cavaciocchi. Prato: Le Monnier, 2003, 488; J. Hatcher, *The History of the British Coal Industry*, 42.

heating made by Englishmen.

The expansion of coal use or rather energy use in general in late eighteenth century British industry was related to technical change in iron production. Charcoal remained the dominant fuel through the seventeenth and much of the eighteenth century. The delay in shifting to coal placed the iron industry behind many others in Britain. From the 1770s and the introduction of the puddling process iron output in England rose dramatically and with it the demand for coal. The shift coincided with the continuing slow diffusion of coke smelting and a turn to the use of steam power in various phases of production.[24] The change to coal use in many phases of iron production was reflected in even more rapid increases in total coal output and a shift in the closing years of the eighteenth century in the share of coal used in industry relative to home heating. It was in exactly those years that England enjoyed rapid economic growth and the signs of structural change in the economy which would induce historians to call it an Industrial Revolution and induce them to locate the roots of modern economic growth in those years. The growth coincided with the increase in coal output and in coal use in industry making

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[24] Ashton, T. S. *Iron and steel in the industrial revolution*. Manchester, New York: Longmans Green & Co., 1924, 87-103, most notably 97; Birch, Alan. *The economic history of the British iron and steel industry, 1784-1879; essays in industrial and economic history with special reference to the development of technology*. London,: Cass, 1967, 27, 33-43; J. R. Harris and Economic History Society. *The British iron industry, 1700-1850*. Houndmills, Basingstoke, Hampshire: Macmillan Education, 1988, 26, 33-40.

it easily possible to confuse the relationship of coal use and economic growth or at the very least to take such a connection for granted.

The early modern European economy relied on a number of different energy carriers. That was certainly true at least in the Dutch Republic and in Britain. The situation may not have been the same throughout Europe but certainly the tendency was for economies to exploit a range of different sources of energy. Economic growth in the period was not based solely on increases in fossil fuel use. It is unlikely that anyone would make such a rash claim but certainly there are reasons to question the relative importance of coal and of peat. The presumption is that more fuel use was a matter of supplying the needs of industry but it would appear that in both Britain and the Netherlands rising demand for home *confort*, as the French came to call it after around 1850[25] in imitation of much older English usage, was a significant factor in rising fossil fuel production. Coal and peat in that case were not producer goods but consumer goods. They were not the sources of rising incomes but rather the result of rising incomes generated in ways not connected to exploiting fossil fuels. If that was true then the obvious question which follows is where did the extra income which paid for higher levels of comfort come from. One energy carrier has been left out of the calculations above and that is the use of wind to power ships at sea. There are two reasons for that. First, it is extremely difficult to estimate how many joules it took to move a ship as Magnus Lindmark, Paolo Malanima and I have all found and that despite using very different methods trying to get some reliable and consistent results. While the variation in the guesses is not wide when compounded with the problems of determining how

[25] A. Pardailhé-Galabrun. *The Birth of Intimacy*, 117.

many ships of what size were in use for how long carrying cargo any result is subject to doubt, and even greater doubt than many of the estimates for fossil fuel use. Second, it is possible to say from our efforts that in absolute terms the contribution of wind power at sea to total energy use was small. Even though commerce got 100% of the force of whatever wind was harnessed moving ships, compared to calories generated by burning coal the amount of energy in total was small. There was one significant difference: wind could move an object. At least until the end of the eighteenth century, there was no way to generate kinetic energy out of thermal energy. Until some kind of steam engine was developed wind powering sailing ships could and did make a unique contribution to the economy. What is more wind use at sea in the Netherlands in the seventeenth century and in Britain in the eighteenth century grew as fast or faster than any other source of power. That includes the use of coal in England (See Figures 6 and 7). The tonnage of the merchant marine of the two Amaritime powers@ grew at a pace as fast or faster than the growth in output of fossil fuels. The Dutch case is confused by the collapse in the size of the merchant fleet in the devastating wars of 1688 to 1714. Growth in tonnage understates the importance of wind as an energy source since the ships were at sea more often for increasingly long periods over time. The contribution from shipping to total energy deployed in the economy in 1800 compared to 1550 was considerably greater than is indicated by the simple measure of growth in total tonnage.

Economic growth in early modern Europe in its most advanced economies relied on a variety of energy carriers and in different and varying proportions over time. Fossil fuel use was critical but by no means the only or even the most important contributor to rising production. The greater output outside the agricultural sector had its origins in the exploitation of a number

of different sources of assistance for human and animal effort. The energy regime was varied and not dominated by one source as would be the case in the nineteenth century when coal was king. The early modern world in the constantly changing diversity of its energy sources was oddly it would seem a world more like that of the twenty-first century.

Tables:

Table 1

Dutch Energy by Source
in millions of kcalories

	1608	1650	1750	1800
Peat	1,750,000+	6,000,000* 1,200,000^	6,000,000+ 1,200,000^	2,680,000+
Coal	30,000+	470,000^	1,700,000^	1,612,500^ 860,000+
Wood	150,000+			1,500,000+
Windmills		45,000*		

*De Zeeuw
^Unger [assume no change in peat conumption 1650 to 1750]
+van Zanden

Table 2

English/British Energy by Source
in millions of kcalories

England:

	1650	1700	1750	1800
Coal	4,280,000	19,800,000	34,250,000	99,645,000
Wood	25,550,000*			
Population (in millions)	5.2	5.5	5.9	8.55

*Assuming an average consumption of 4 kgs of firewood per day with the level presumably approximately stable through much of the eighteenth century.

Source: For coal output John Hatcher, *The History of the British Coal Industry*, 41; David Ormrod, *The Rise of Commercial Empires*, 252-254; Michael W. Flinn, *The History of the British Coal Industry*, 26. For population data E. A. Wrigley and R. S. Schofield, The Population of England 1541-1871 A Reconstruction, Cambridge,1989, 574, 577.

Table 3

Estimates of Per Capita Thermal Energy Consumption
(kcals/person/year)

England (Britain):

	1650	1700	1750	1800
Coal	855,000H	3,920,000	6,000,000	11,500,000

Holland:

	1550	1608	1650	1700	1750	1800
Coal		50,000*	255,000^		850,000^ (888,000)	400,000*
Peat	2,785,000+	2,880,000*	630,000^		630,000^ 2,150,000*	1,250,000*
Total	3,344,000+	3,200,000*	985,000^		1,480,000^ (1,518,000)	2,350,000*
			3,965,000!			

_Underestimate based on exports from northeast ports
*Van Zanden
^Unger (Ormrod adds 10-20,000 tons to English coal imports around 1750)
[Assume no change in peat consumption 1650 to 1750]
+Cornelisse [the figure for 1500 is more or less the same]
!De Zeeuw

Table 4

Estimated Efficiency of Energy Carriers

	Percent of latent energy in power sources available for work
Draught Animals	10
Human Beings	20
Firewood	20
*Coal	30
*Peat	30
Water & Windmills	100
Wind (ships)	100

*Subject to variation depending on the burner

Table 5

Coal and Peat Energy Use in Industry
Dutch Republic and England
1608-1800

Dutch:		English:	
Energy Use	Kcals/Person	Energy Use	Kcals/Person

	Per caput	Used in Industry	Per Caput	Used in Industry
1608	3,344,000	2,240,500		
1650	985,000	659,950[2,656,500]	855,000	342,000
1700			3,920,000	1,568,000
1750	1,518,000	1,017,000	6,000,000	2,400,000
1775			9,300,000	3,720,000
1800	2,350,000	1,574,500	11,500,000	4,600,000

Share in Industry: The Dutch Republic = 0.67, England = 0.4
[De Zeeuw]

Table 6

Energy Sources in Holland c. 1650

	Kcals/person/ year	Share to Industry	Efficiency	Net Contribution to Industry per cent kcals/person/year
Peat	630,000^ 3,965,000_	.67	.30	422,100^ 2,656,550†
Windmills	23,684	1.00	1.00	23,684

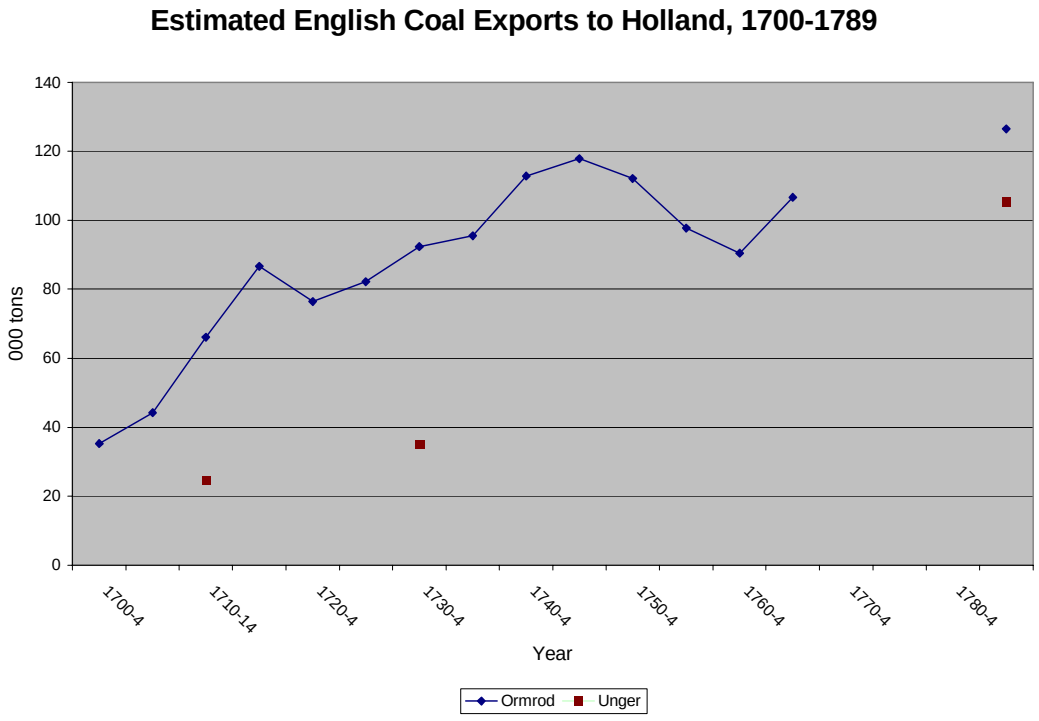
^Unger
†DeZeeuw

Table 7

London Energy Use Per Capita, 1637-1800

Year	Coal Imports(tons)	Population	Kcals/person
1637-8	283,375	350,000	6,100,000
1699-1700	469,160	550,000	6,400,000
1750	677,000	750,000	6,770,000
1800	1,234,000	950,000	9,700,000

Figure 1



Source: David Ormrod, *The Rise of Commercial Empires*, 254.

Figure 2

Source: John Hatcher, *The History of the British Coal Industry*, 497.

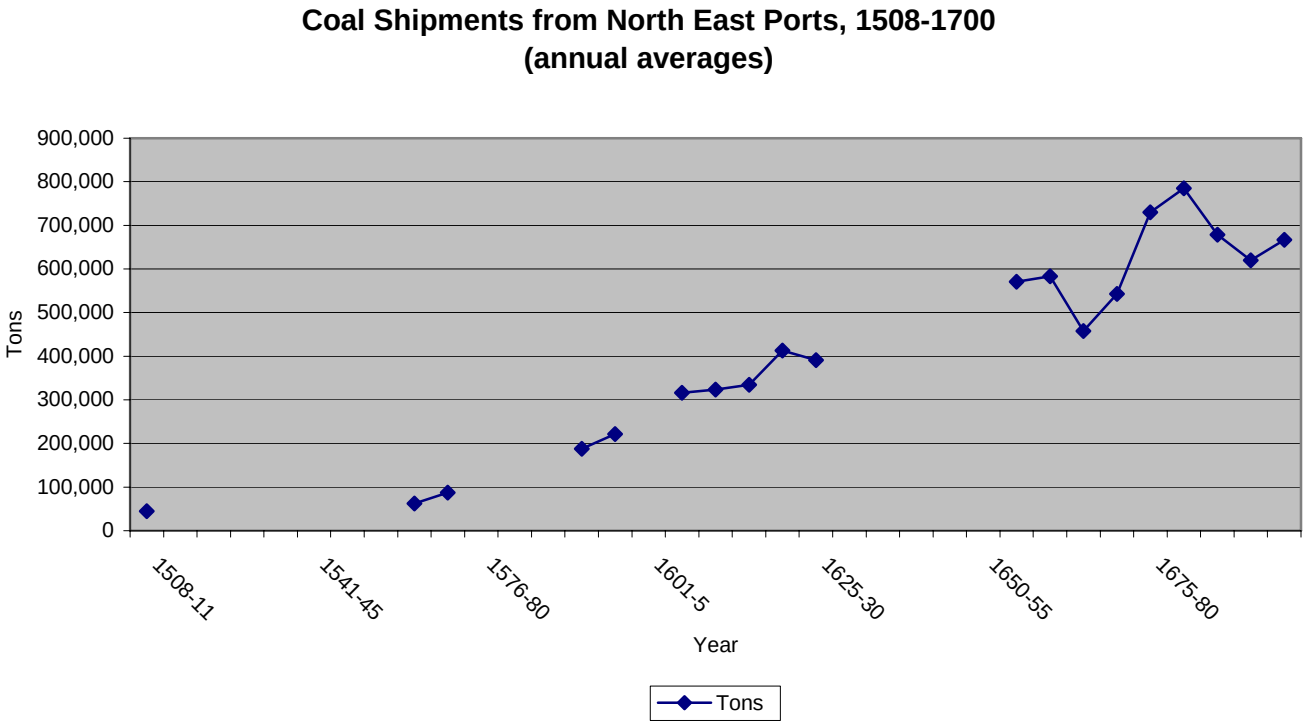
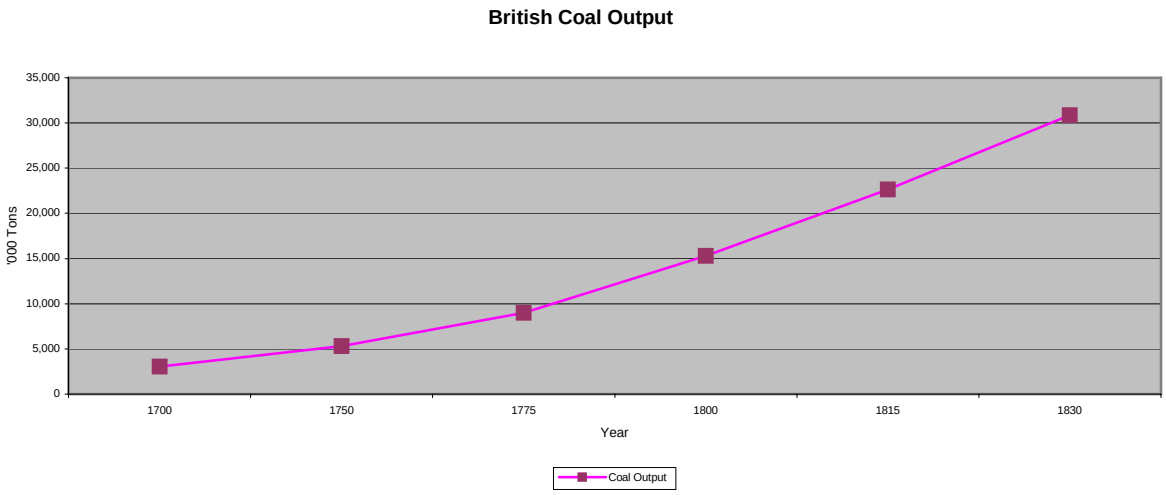
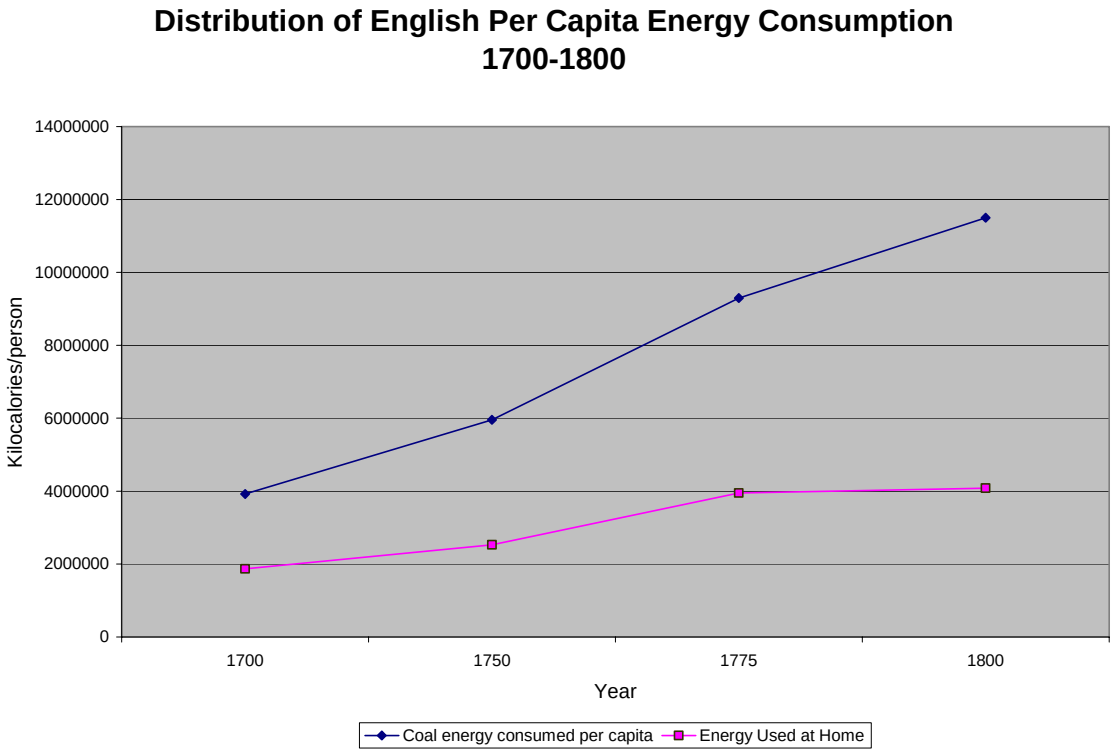


Figure 3



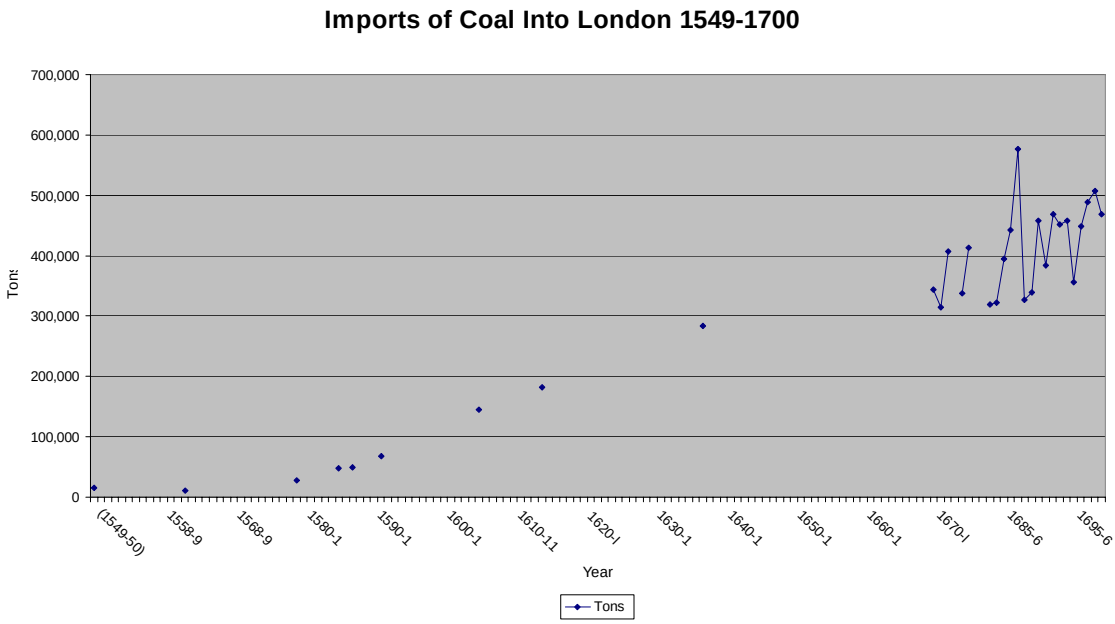
Source: Michael W. Flinn, *The History of the British Coal Industry*. Vol. 2 1700-1830: The Industrial Revolution. Oxford: Clarendon Press, 1984, 26.

Figure 4



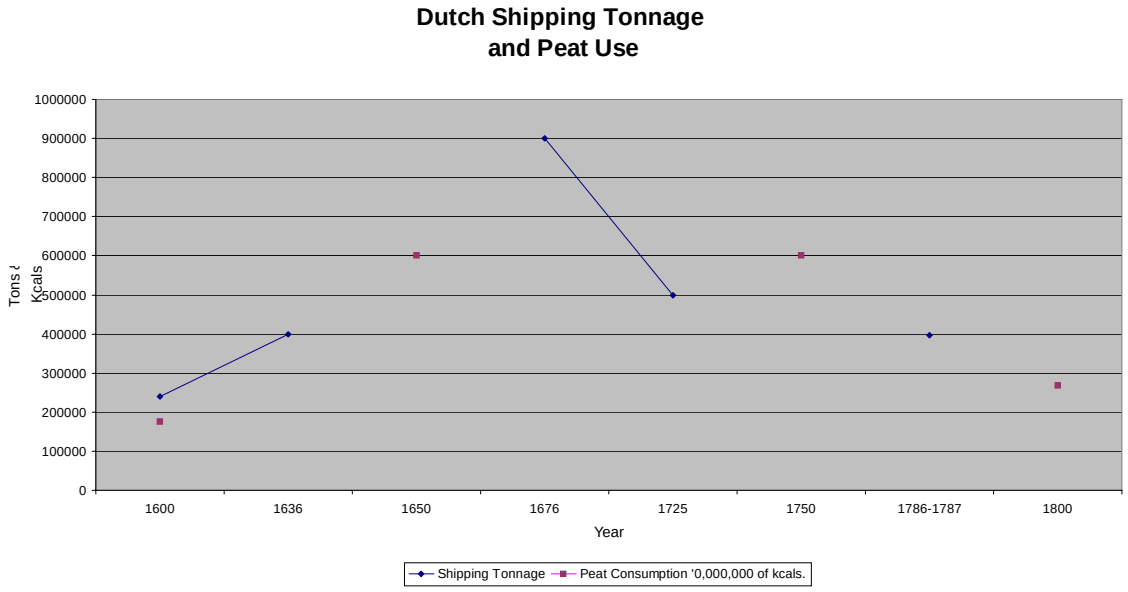
Source: Michael W. Flinn, *The History of the British Coal Industry*. Vol. 2 1700-1830: The Industrial Revolution. Oxford, 1984, 252.

Figure 5



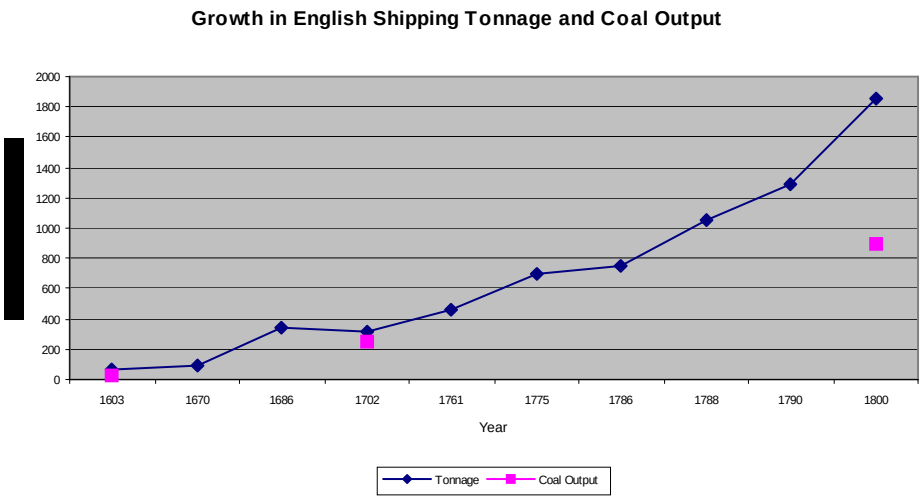
Source: John Hatcher, *The History of the British Coal Industry*. Vol. I . Oxford:, 1993, 501-502.

Figure 6



Sources: J.L. van Zanden, ‘Werd de Gouden Eeuw uit turf geboren? Over het energiegebruik in de Republiek in de zeventiende en achttiende eeuw’, in: *Tijdschrift voor Geschiedenis* 110 (1997); Richard W. Unger, "The Tonnage of Europe's Merchant Fleets 1300-1800," *The American Neptune*, 52, 4 (Fall, 1992).

Figure 7



Sources: Ralph Davis, Rise of the English Shipping Industry, London: 1962, 27; Michael W. Flinn, *The History of the British Coal Industry*. Vol. 2 1700-1830: The Industrial Revolution. Oxford, 1984; John Hatcher, *The History of the British Coal Industry*. Vol. I . Oxford:, 1993.