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Divergences in the Long Run Trends in the Price of Energy and of Energy Services

Roger Fouquet

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Roger Fouquet

Email: roger.fouquet@bc3research.org

Divergences in the Long Run Trends

in the Price of Energy and of Energy Services

Roger Fouquet[1][2]

This paper presents new evidence on the very long run trends in the price of energy and energy services, such as heat, power, transport and light. The paper has two purposes. First, it shows that, in general, there was an upward trend in average energy prices leading up to the Industrial Revolution and a decline afterwards, associated with the shift from traditional energy sources to fossil fuels. At the end of the nineteenth and early twentieth centuries, however, average energy prices did rise, reflecting (not rising resource scarcity but) greater value to consumers, as they shifted to energy sources that provided the desired services more efficiently.

Second, the paper highlights the dangers of focussing on the price of energy, rather than the price of energy services, when considering the long run. The price of energy ignores the major technological improvements that have occurred and that benefit the consumer. This failure to focus on the services is likely to lead to incorrect estimates of consumer responsiveness to changes in price and income. This paper suggests that the inclusion of service prices and consumption variables would lead to more reliable models of long run energy demand and forecasts of carbon dioxide emissions.

Keywords: energy prices; long run; technological innovation, climate change

JEL Classification: E31, N53, O33, Q21, Q32, Q41, Q55, R41

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[1] Basque Centre for Climate Change (BC3). Gran Via 35 – 2, 48009 Bilbao, Spain. Email: roger.fouquet@bc3research.org

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1. Introduction

Fears of resource scarcity and climate change have highlighted the importance of taking a long run perspective on energy issues. Energy prices in the first decade of the twenty-first century have risen rapidly, raising concern about their impact upon the economy. Questions must be asked about whether they will continue to rise and what will be the long run trend in energy prices. One way to develop an expectation of future trends is to place these increases within a historical context.

Numerous studies have examined the long run trends in commodity, resource and energy prices. Barnett and Morse (1963) looked at the real average costs for a number of mineral, agricultural and renewable resources in the USA between 1870 and 1957, and that all but three of the prices had remained constant or fallen. William Nordhaus´ (1974) empirical results corroborated this initial survey. Smith (1979), Slade (1982), and Berck and Roberts (1996) studied non-renewable resource price trends over periods of more than one hundred years. In more detailed statistical analyses, they found that the trends tended to vary according to the samples. Pindyck (1999) investigated US oil, coal and natural gas prices over 127 years and found that, while a U-shaped regression could explain trends up to the 1980s, it over-estimated the prices in the last fifteen years of the twentieth century. Adelman (1995) analysed consumer oil prices for over eighty years and crude prices for more than one hundred and thirty years, and concluded that it was difficult to reconcile the evidence with a theory that oil is a limited resource. Krautkraemer´s (1998) review of the literature proposed that the discoveries of new deposits, technological progress in exploration and in use, as well as the development of substitutes implied that the finiteness of resources does not directly influence the economic scarcity of the commodity.

One could argue, however, that one hundred years is too short a period to test the theory. Despite the difficulties of creating them, and the compatibility of values within the series, longer series have been built. Hausman (1995) spliced consumer and producer prices series to create a very long run series from 1450 to 1988. He found no support for the view that fuel prices were rising over the very long run, and that when individual fuel prices have risen, consumers have switched away from the dearer fuel. Fouquet and Pearson (2003) also presented trends in individual fuel and average energy prices since 1500. They showed that there was little evidence of systematic or substantial rises in individual fuel prices. However, the second half of the nineteenth century and the early years of the twentieth century were characterised by an increase in the real average ‘energy’ price. During the period, energy systems were dramatically altered with large scale substitution towards more expensive but higher ‘quality’ fuels. It was reflected in the growing share of petroleum, gas and ultimately electricity in final user expenditure on energy over the period. So, a possible explanation for this price increase, rather than being associated with rising scarcity, was the growing value consumers placed on the energy being consumed.

It has been proposed that price trends are useful indicators, but not the most reliable for examining the scarcity of resources. The rent (also known as the royalty, net price or marginal profit) – that is, the difference between the price and the marginal extraction cost - is a more accurate indicator (Krautkraemer 1998). Similarly, as this paper will conclude, for understanding and anticipating long run trends in energy use and forecasting carbon dioxide emissions, energy prices may not be the most appropriate variable to reflect the burden imposed on and the incentive facing the consumer.

Nordhaus´ (1997) paper pointed out the potential danger of focussing on the price of energy rather than of energy services – in the case of lighting, it ignored major technological improvements. By focusing on energy prices, he showed that it dramatically underestimated the decline in the cost of lighting over the last two hundred years and the ensuing welfare gains to the consumer.

Demand for energy stems from the needs for energy services, such as heat, power, transport and light. To provide these services, it is necessary to combine energy with the appropriate equipment, be it a hammer with muscular strength, a harness with horse power, sails with the wind, or a train with steam, diesel or electricity. When the efficiency of the technology improves, the price of the service falls, even if the price of energy remains unchanged. Fouquet (2008) presented a great deal of evidence on long run trends in energy service prices and consumption. It did not, however, explicitly show that the perils of focussing on energy (rather than energy service) prices applies for all energy services.

This paper presents long run trends in energy prices from the fourteenth century to the present day, in what was to become the United Kingdom, and compares them with the prices of their associated services. It draws conclusions about trends in the long run price of energy and its services, and their tendencies to diverge.

In the next section, some of the theoretical expectations about trends in energy prices are presented. The following section points the reader towards the secondary and original sources for the data and briefly explains the methodology for estimating energy service prices. The subsequent sections present the trends in the price of heating fuels and heating, first, then for other energy services and for average ‘energy’. This provides the context for a brief comment on current long run trends in energy prices. Then, the divergences in trends are considered more generally. The final section reflects on the implications of divergent trends.

2. The Price Signal

Prices indicate a commodity or service's relative scarcity and value. Trends in prices are likely to reflect changes in value and scarcity. It is worth briefly considering how energy prices might be expected to trend. Here, the purpose is not to delve deeply into the theory of resource extraction, but rather to build a bridge between the theory and empirical evidence on price trend determination. Three cases will be useful to consider: unlimited, non-renewable and renewable resources.

2.1. Unlimited Resources

The first case is where resources are effectively unlimited – either because the production is very small relative to the size of the resource base or the producers do not perceive their resources to be finite. With many firms competing, the individual producer´s decision, unconcerned about intertemporal extraction problems, would be to increase production until marginal costs equal the price - the standard profit maximisation decision in a perfectly competitive market (Gravelle and Rees 2004).

As is common to many industries, long run marginal and average costs would tend to decline as production increases (reflecting economies of scale) and then rise (as the production process becomes less efficient). In other words, the curves would be U-shaped. In the long run, the price the producer faces would tend to stabilise at the lowest long run average cost (i.e. the bottom of the U), because firms will enter the market if the price rises any higher, thus, increasing supply.

In a growing economy (Y), demand (D) will tend to rise through time. The change in price (p) will be a function of the ratio of the change in demand to the change in supply (S).

$$\frac{\partial p}{\partial Y} = f\left(\frac{\partial D}{\partial Y} / \frac{\partial S}{\partial Y}\right) \qquad (1)$$

In this case of effectively unlimited resources, capital and labour, increases in demand will eventually be met by an expanding supply. The long run price elasticity of supply would be infinite. The only increases in price would be associated with temporary readjustments in the production and supply infrastructure. In the long run, prices would not be expected to rise.

Long run average costs and market structure may affect the long run price, though. If, for instance, long run average costs tend to decline greatly, then only one or a few producers and suppliers can compete, which can lead to higher prices. Unless there was a gradual increase in industrial concentration, this would lead to a once-and-for-all rise in prices – not a rising trend.

Similarly, prices could fall if the long run average cost curve shifts downwards. Improvements in production processes may drive down these costs, implying temporary profits for innovators while prices remain stable. In time, imitators will enter the market and prices would fall to the new lowest long run average cost. Consumption may increase in response to the declining pressure on prices – but unless demand is perfectly elastic as well, prices will fall. Thus, in the case of perfectly elastic production and supply with effectively unlimited resources, the prices might be expected to fluctuate considerably around stable downward steps.

Declines in demand could result from downturns in the business cycle. This would imply downward pressure on prices. Thus, prices could be expected to fluctuate following the business cycle.

A more long term downward pressure on demand could be driven by improvements in the efficiency of consumption. Working against this pressure would be possible rebound effects and general economy growth in demand. If demand did fall, so would prices, initially. However, if the production side was perfectly flexible, supply would adjust downwards. Thus, prices may not necessarily fall in the long run following an improvement in the efficiency of consumption.

2.2. Limited Renewable and Non-Renewable Resources

With unlimited resources, the producer extracts to meet the demand. If resources are limited, the producer´s decision-making process will change. The producer needs to decide at what rate to extract resources to maximise profits.

When they are non-renewable, Hotelling´s (1931) principle proposes that the incentive (for the producer) is to extract more resources as long as the rate of increase in future expected net prices (that is, price minus costs) is lower than the discount rate – the opportunity cost of not extracting and selling resources. Expectations of relatively low future net prices will encourage additional extraction today and tend to put upward pressure on current production and supply. Rapid exploitation today will mean future fuel reserves will be lower, driving up expectations of future prices. If the expected annual rise in net prices becomes greater than the discount rate, managers will have an incentive to invest in fuel reserves by keeping them as stocks. With the stock limited, Hotelling´s principle suggests that net real prices will rise through time (Medlock 2009).

The basic model of resource extraction has been extended to incorporate numerous important variables: the existence of costs of exploration and extraction (the basic model assumes zero costs) and of a ‘back-stop’ technology (providing a more expensive yet inelastic fuel substitute); either increasing or decreasing marginal costs of extraction (because of greater difficulty in extracting the next unit and varying resource quality or due to technological improvements); changes in the discount rate; increases in reserves or in demand; market structure such as monopolies or cartels; and uncertainty about demand, reserves or institutions (Krautkraemer 1998).

All of these extensions alter the optimal rate of extraction. For example, a 'back-stop' technology provides the upper limit for the cheaper fuel's price; lower costs of extraction will lower the initial price, but raise the rate of growth in future prices; higher discount rates will have a similar effect; new discoveries will reduce the price range, as well as the rate; new demand will have the opposite effect; monopolies are likely to reduce the rate of extraction, creating a higher initial price with a lower eventual price. All these factors will have their role in determining the price path, which may be rising, downward-sloping or U-shaped (Farzin 1992).

If resources are limited and renewable, producer will tend to extract resources to ensure that the rate of growth of the resource is equivalent to the discount rate. In a growing economy, it would be expected that demand would eventually reach the limit at which resources can be renewed and profitably harvested. Then, as demand continues to grow, increases in the resource stock and efficiency improvements in production (as well as on the demand-side) are necessary to avoid demand outstripping supply. Otherwise, prices would be forced upwards (Fisher 1981).

2.3. Other Price Issues

Naturally, the price the consumer faces is higher than the production costs - marked-up by distribution costs and taxation. Through time, transport costs may be expected to decline as economies of scale are achieved. Beyond a certain scale, though, gains will be limited and costs will tend to stabilise. However, energy efficiency or institutional improvements may continue to drive down costs. Taxation is likely to be a one-off increase. There may be gradual increments in the rate of taxation, but they probably eventually stabilise for political reasons.

A further point is the difference between individual energy prices and an average price, which is a weighted average of different sources. When an individual fuel price rises, consumers will substitute, to some extent, to other cheaper sources. This will change the weighting of sources and, thus, the average price. So, long run trends in individual fuel prices may not imply similar increases in average prices.

Finally, the consumer is interested in the services generated (heat, power, transport and light, for instance), rather than the amount of energy used. As mentioned before for transportation, efficiency improvements can be expected to continue, as there are always incentives to introduce better ways of consuming energy. Consequently, the price of the service should decline. As discussed early following efficiency improvements, energy demand may be subject to rebound effects, and an elastic supply would adjust to changes in demand. So, the price of energy would probably not fall by as much as the price of energy services as long as efficiency improvements are possible. This paper seeks to identify whether trends in the prices of energy and of energy services did diverge.

3. Data

Identifying trends in the evolution of the cost of energy services requires statistical information on prices and consumption of heating, power, transport and lighting fuels, on energy technologies and their efficiencies. Details about the principal sources and methods used to assemble the data series associated with fuel prices and technologies can be found in detail in Fouquet (2008).

The only additions to this dataset are extending back in time (to the year 1300) and improving the data on the price of coal and firewood, based on a dataset used for Clark (2007). Also, the retail price index is now based on a dataset used for Allen (2007).

It is worth, however, pointing-out the general sources of the data. There is a considerable amount of annual or periodic information on the history of energy services in Britain, collected from markets, schools, colleges, hospitals and government departments around the country, going back many centuries. Just to mention the most frequently used sources, they are Rogers (1886), Beveridge (1926), and Mitchell (1988). However, despite their relative richness, it is necessary to stress that the data presented and discussed below should be interpreted with caution. Especially for the early centuries, the data are often drawn from the records of one or a few institutions that bought fuel for lighting in the South of England, and so are not representative of Britain as a whole. In some other cases, the data are interpolations based on information for previous and later years. In particular, while ‘annual’ data for ‘the United Kingdom’ are shown, there are considerable margins of error and data gaps, notably before the mid-nineteenth century. Hence, it is wiser to focus on the broader trends and the orders of magnitude differences over several decades or one technological revolution and the next, rather than on individual year-on-year changes.

The conversion of the price of fuels into their equivalents in energy services requires combining them with energy efficiency of the equipment used for each service. For example, in the eighteenth century, a tonne of coal could be placed in a traditional fireplace and burnt, generating around ten percent of a tonne of coal in useful heat. With this data, and knowing that the price of one tonne of coal (in 2000 money) was equal to £145, one can estimate the price of one tonne of coal equivalent of useful heat – about £1,450.

Thanks to Allen´s (2007) dataset, the costs of using different fuels and of producing services are broadly comparable across time throughout the paper, and prices are quoted in real terms for the year 2000. Again, all information about the sources and the process for estimating service prices can be found in the appendix of Fouquet (2008).

4. The Price of Fuels and of Heating

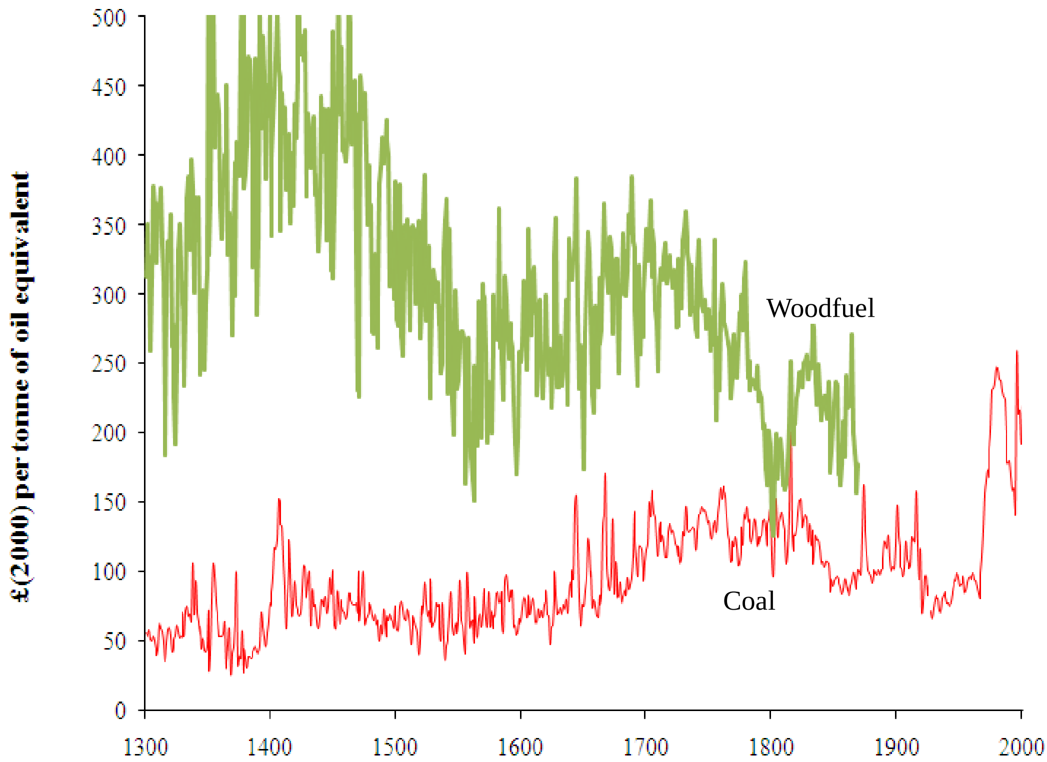
Figure 1 offers some evidence on long run trends in fuel prices, which provided the heat in homes and for industries. Starting with woodfuel prices, they clearly react to market pressures. In the fourteenth century, rising population put major pressures on woodfuel supplies. After the Black Death, and the dramatic decline in population, woodfuel prices fell. They started rising as the population grew again in the sixteenth century. Given the experience in the 1300s, woodfuel prices would have risen much higher (above £300 in real terms) if there had not been a shift towards coal from the sixteenth century.

For coal prices, the evidence suggests a rising trend in coal prices between 1600 and 1800. It does, however, hide the fact that the price series is an aggregate of prices in different regions of England. It is worth inspecting what lies beneath this rising trend, to understand whether it reflects rising scarcity or other forces at play.

From 1500, coal prices in the North of England stayed close to £(2000)40 per tonne for three hundred years (see Figure 2). This series appears to be similar to the pithead price, providing an indicator of long run marginal cost of production. There is no evidence of rising marginal costs of production over hundreds of years.

Thus, the rising trend in the national average price of coal between 1600 and 1800 (shown in Figure 1) has another explanation. It is the result of, first, the growth in coal consumption in London that increases the weighting of the London price series, where prices were highest, and, second, the increase in consumer prices (i.e. for London and the rest of England) rather than pithead prices (see Figure 2). The main reason for this rise is the imposition of taxes on coal from the late seventeenth century – by the mid-eighteenth century, they accounted for a third of the consumer price (Hausman 1987 p.592).

Figure 1. Woodfuel and Coal Prices in England (1300-2000)



So, coal prices increased as consumption grew. However, this reflected government´s ability to capture some of the consumer surplus associated with a relatively inelastic demand and supply, not growing scarcity of resources. At times, there was upward pressure on prices but supply adjusted to accommodate demand. In fact, after 1800, prices tended to fall, as new regions began to exploit coal resources, helped by the invention of the steam engine which could pump out the water mechanically from ever-deeper coal mines. Thus, the evidence here suggests that to accept a simple theory of long run prices that proposes an upward rising trend is misguided.

In addition to regional variability, coal quality varied greatly. Unfortunately, there is little information on the long run trends for different varieties of coal. If it did, a hedonic price model could be used to estimate, for instance, changes in consumer willingness to pay for low-smoke coal, such as anthracite – an indicator of past demand for environmental quality.

Figure 2. Coal Prices across England (1300-1870)

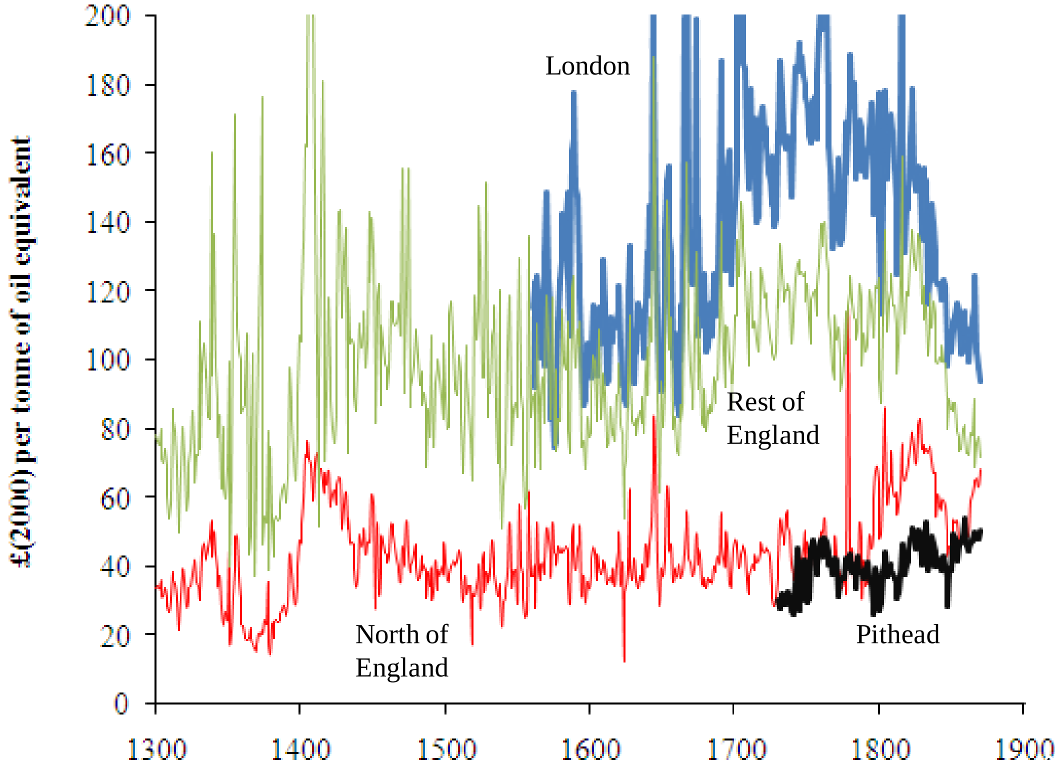
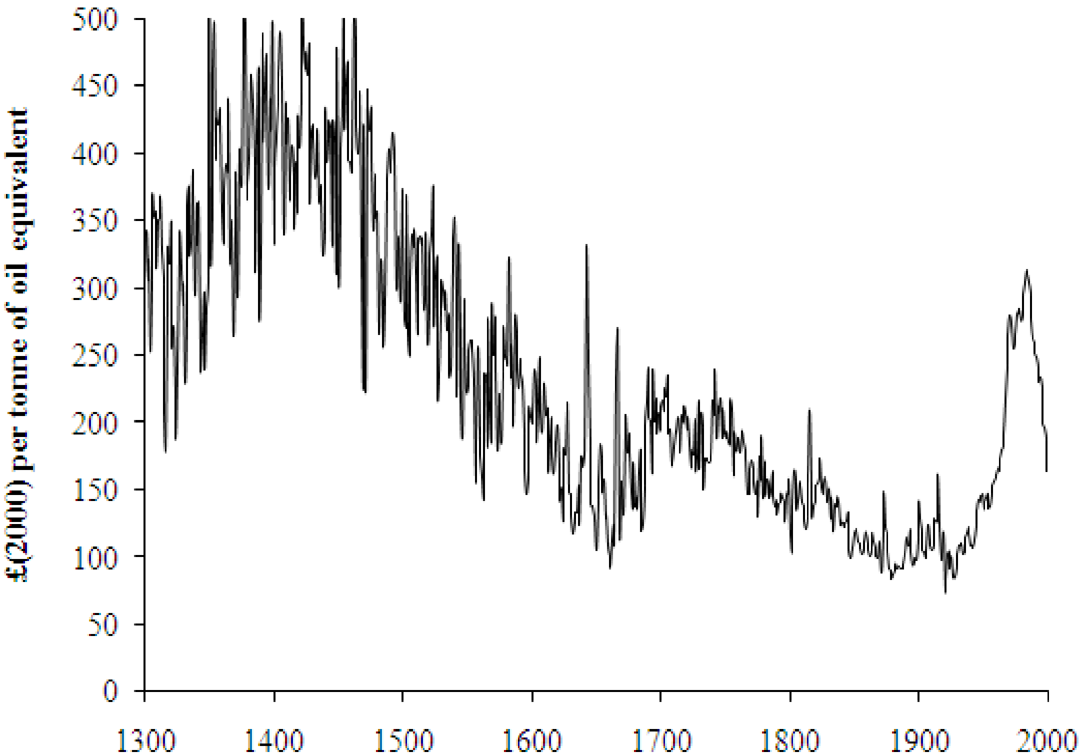


Figure 3 presents average heating fuel prices. This is weighted by expenditure (i.e. price multiplied by consumption) on fuels. Estimates of consumption and expenditure only begin around 1500, when the first estimates of coal production offer a glimpse of the scale of the market (Hatcher 1993). Also, Warde (2007) provides estimates of total woodfuel consumption, based on the potential production from wooded areas, from 1560 onwards. Estimates of woodfuel and coal consumption sectoral shares between 1500 and 1700 are based on Fouquet (2008).

For the fourteenth and fifteenth centuries, when no consumption data was available, the weightings for 1500 are used. At the time, the estimates suggest woodfuel was responsible for 98% of heating expenditure. This is an acceptable assumption since the transition to coal began in the sixteenth century and there was probably little change in heating fuel use before this period.

For coal consumption between 1700 and 1830, Flinn (1984) presents more reliable estimates. Since the mid-nineteenth century, national statistics have been provided for coal and then gas.

Figure 3. Energy Prices for Heating in England (1300-2000)



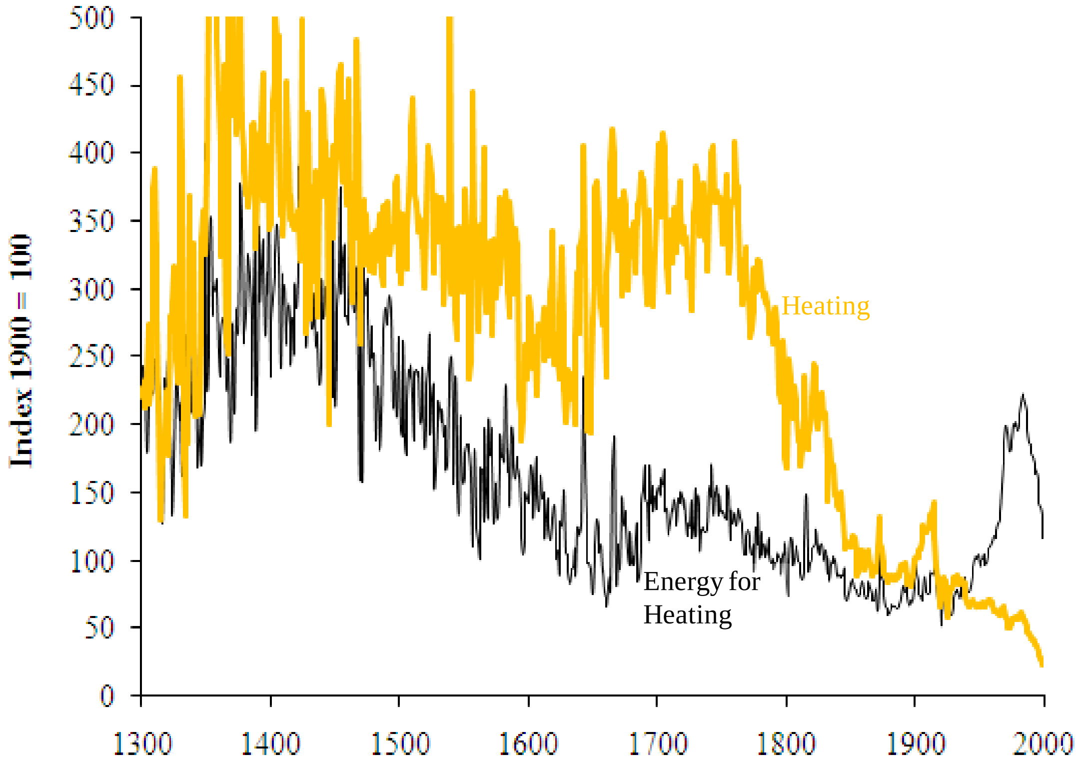
Between 1300 and 1550, woodfuel prices dominated. The next two centuries were associated with the transition to coal. Since coal was roughly half the price of woodfuel, the switch implies a declining trend in average prices, despite a rising coal price.

Figure 4 presents the trend in average household heating prices, as well as for fuel prices. They are estimated by combining the prices of individual fuels and the efficiency of the relevant technologies. The average price is calculated by weighting the individual heating prices by household expenditures´ for the different methods of heating. The unit of measurement is an effective tonne of oil equivalent – that is, the heating from one tonne of oil using equipment with an efficiency of 100%; thus, the lower was the efficiency, the higher was the price of heating (for a given fuel price). In Figure 4, this is presented as an index (1900 = 100), to aid comparison with the trend for heating fuel prices.

The trends in the price of heating followed the peaks and troughs in the price of heating fuels between 1300 and 1750. However, for consumers to shift to the far cheaper fuel, coal, they needed to switch to a less efficient technology – from the hearth to the fireplace, which could get rid of the noxious coal smoke more effectively. This implied that, over those 450 years, the price of fuels fell more than the price of heating. Nevertheless, it enabled heating prices to fall, which would not have been possible if consumers had kept on using woodfuels.

In the nineteenth century, the efficiency of heating equipment started improving greatly, thanks to the widespread adoption of the Rumford fireplace (Crowley 2004). In the twentieth century, the improvement in efficiency intensified, and ultimately led to the highly efficient central heating boiler. So, despite the gradual switch towards more expensive energy sources for heating, electricity and gas, in particular, heating prices fell. Thus, to focus on the price of energy (not the service price) is misleading.

Figure 4. Price of Heating in England (1300-2000)



An important lesson here is that average energy price trends can deceive, hide and mislead a great deal: first, average coal prices increased for 200 years in great part because of the growing demand in London and the taxes imposed on this market; second, for 500 years, the trend in average heating energy prices was downwards, hiding, yet reflecting, the transition to fossil fuels; third, the rise in average heating energy prices misleads us into thinking it cost more to heat homes, when the greater efficiency of heating technologies lowered this cost.

Yet, a key point is that average energy prices will have a tendency to fall in the long run because the consumer seeks the cheapest choice, and will substitute fuels to achieve this, if necessary and possible. Similarly, the supplier has an incentive to provide those resources cheaply in order to increase the firm´s profits and market share. But, even more clearly the price of heating will tend to fall. Ultimately, the consumer is interested in the price of the service provided, not the fuel. Thus, to focus on the price of heating fuels rather than the price of heating can be misleading, especially in times when important differences in the efficiency of the technology exist.

For heating, as Nordhaus (1997) argued for lighting, the price of the service fell far more than the price of the energy source. In fact, with heating, price actually rose. Thus, a compelling case can be made for focussing on the service rather than on the fuels. It is now necessary to consider the prices of other energy services and comparing their long run trends with those for their related energy.

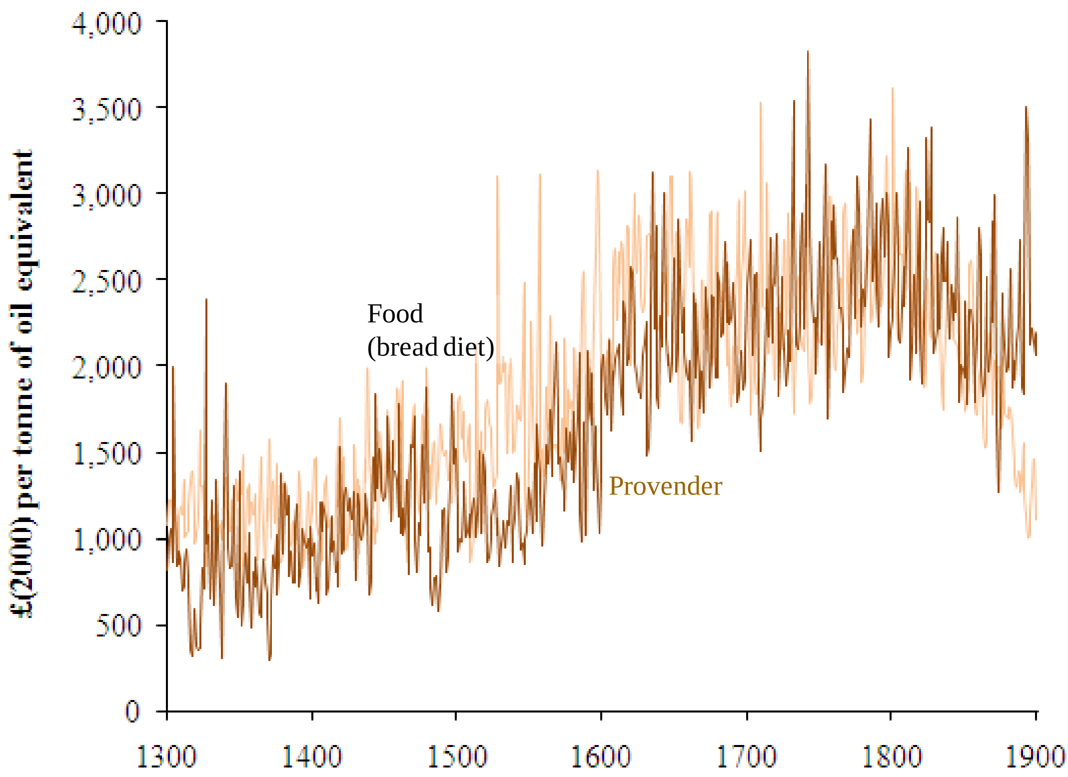
5. The Price of Energy and of Energy Services

First, it is worth taking a look at the price of the main energy sources for power services (see Figure 5). Until the Industrial Revolution, humans and animals provided close to nine-tenths of all the power needs. Energy for humans and horses were quite similar. Food (i.e. a diet of bread) prices increased during the sixteenth century. Similarly, horse provender (i.e. a combination of hay, oats and peas) prices, starting from a lower level, rose rapidly during the sixteenth century. This rising trend reflected the growing population of humans and animals requiring crops to feed them.

The price of power followed its energy prices very closely until 1700 (see Figure 6). Energy (i.e. food and fodder) prices (on left axis) rose particularly rapidly in sixteenth century and remained high until 1800. From the beginning of the eighteenth century, the price of power (i.e. the cost of hiring workers and animals), shown on the right axis, started declining as better horse-breeding led to more efficient animals working the land and industry. Between 1820 and 1835, the price of power rose sharply, reflecting a higher real wage (due to rapid deflation) and a doubling of the labour force (increasing the weight of human as a share of overall power). This peak no doubt encouraged employers to use steam engines, where possible.

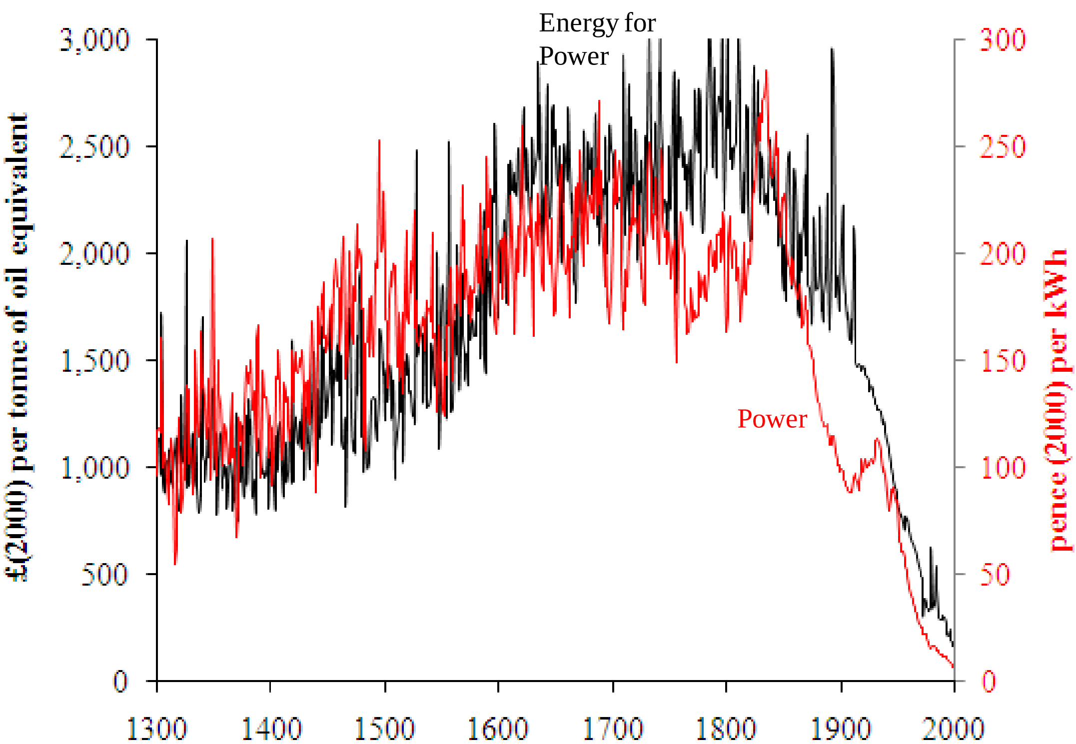
The cost of using energy to generate power fell during the nineteenth century as the dominant source of energy for power shifted from fodder to coal, which was roughly twenty times cheaper. Until the mid-nineteenth century, steam engines were more inefficient than horses at converting energy into power. Yet, they were still cheaper at generating power. In addition, the steam engine offered a concentrated method of production, which the horse could not offer. This enabled cost reductions in other aspects of the production of the final product, especially for cotton, before the mid-nineteenth century. However, widespread use of steam power only took place in the second-half of the nineteenth century, as the steam engine´s efficiency tripled between 1850 and 1900. The price of steam power fell four-fold in that period, and the average power price halved.

Figure 5. Prices of Food and Provender in England (1300-1900)



Surprisingly, however, the average price of energy fell faster than that of the service during the twentieth century. The principal explanation is a technical one, though. Humans and animals still played a role at the beginning of the twentieth century. Given their inefficiency at converting energy into power, expenditure of food and provender was great (relative to their share of power provision). This heavily weights the fuel price series, but not the power series. After the First World War, their role in power provision declines significantly over the next fifty years and effectively disappears at the end of the twentieth century. If observed from 1800 to 2000 (before the diffusion of the steam engine), the price of power fell more (25-fold) than the fuel costs (14-fold).

Figure 6. Prices of Energy (for Power) and of Power in the United Kingdom (1300-2000)

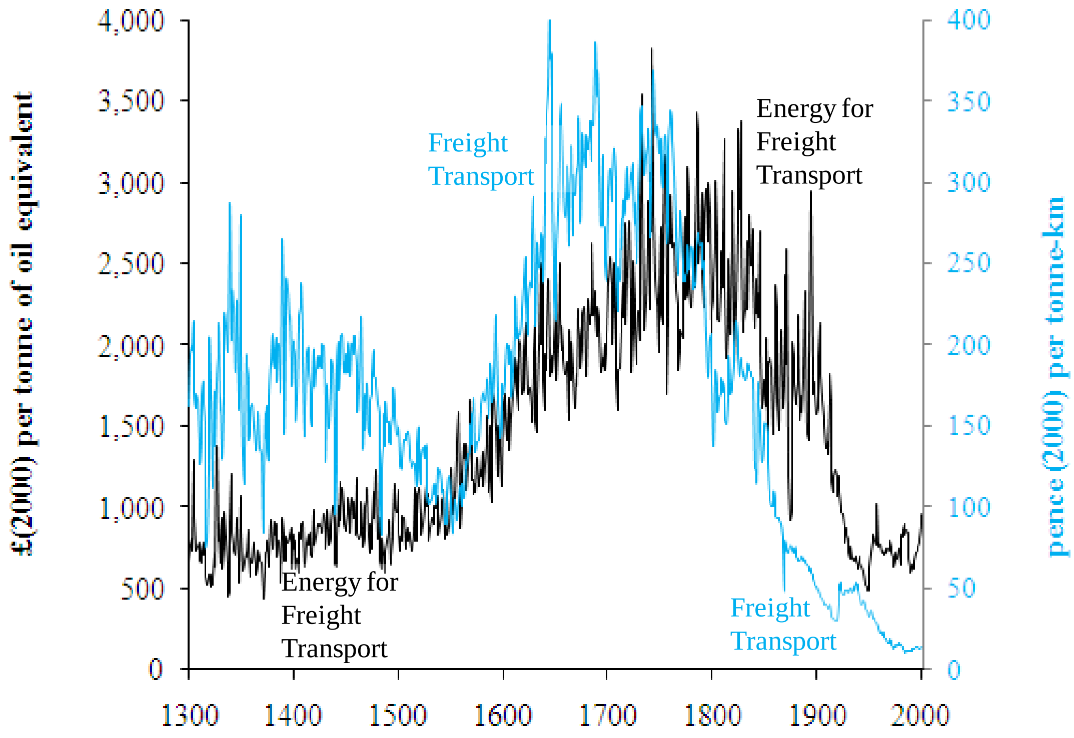


Also, the prices of power from horses and from humans were both measured by the cost of using them. For humans, this was the wage rate taking account of the power generated by a labourer. For horses, this was the annualised cost of using a horse (mostly provender and maintenance) divided by an estimate of the power generated in one year. For steam engines, which dominated at the end of nineteenth century, similar annualised costs are estimated. For both horses and steam engines, the exclusion of capital costs underestimates the full cost of generating power – but, only by about 10% to 20%. For electricity, however, the price that the consumer faces is used. This price includes the profits to the electricity producer and supplier, and the taxes imposed, as well as the costs of keeping reserve capacity, of a complex supply network and of inefficiencies in distribution.

Thus, in the twentieth century, the rate of decline in the price of power was slower than for the fuels that drove it. This reverses Nordhaus´ (1997) argument – although it supports his view that it is necessary to focus on services rather than the commodity. Both in the nineteenth and twentieth centuries, the trends in the prices of energy for power and of power were distinct, and, in the long run, to use the former when the latter drives demand for power and for the associated energy is likely to generate a misleading understanding of consumer responses.

For transport, the long run trends in the price of energy and of freight services are even more divergent (see Figure 7). Using the left-axis, the price of energy (fodder until the mid-nineteenth century, coal until the mid-twentieth century and then oil) followed a similar trend as the price of energy for power. Based on the right axis, the price (i.e. the marginal cost to the consumer) of transport services, were not only dependent on the costs of the fuel. The quality of the transport infrastructure and network were another crucial component, and declining quality explains much of the rise in the sixteenth and seventeenth centuries. Once turnpikes (i.e. privately-provided public goods) were introduced, quality improved and prices fell. They also fell further after the introduction of railways, and have continued to fall in the twentieth century.

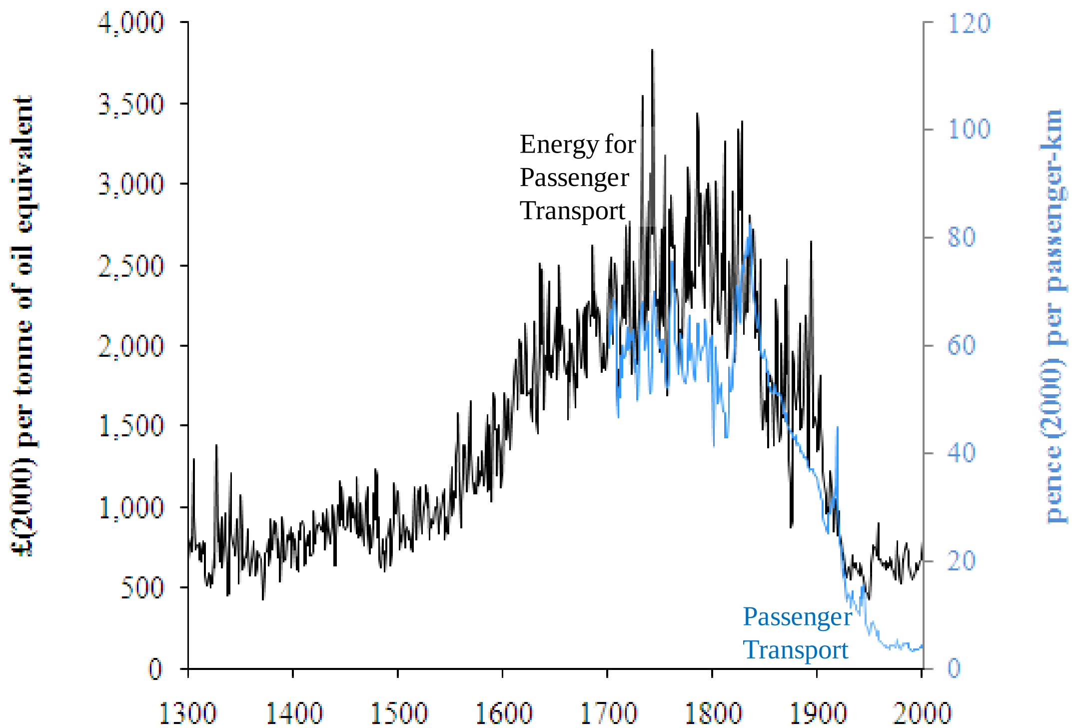
Figure 7. Prices of Energy (for Freight Transport) and of Freight Transport in the United Kingdom (1300-2000)



Even though the trend in energy prices (increasingly associated with oil) was not downwards in the second-half of the twentieth century, improvements in vehicle efficiency implied cheaper transport services. Like for heating, consumers experienced declining trends in the cost of providing the service, despite rising or flat trends in energy prices. Once again, to use the latter to study long run transport demand, and the related fuel consumption, would be misleading.

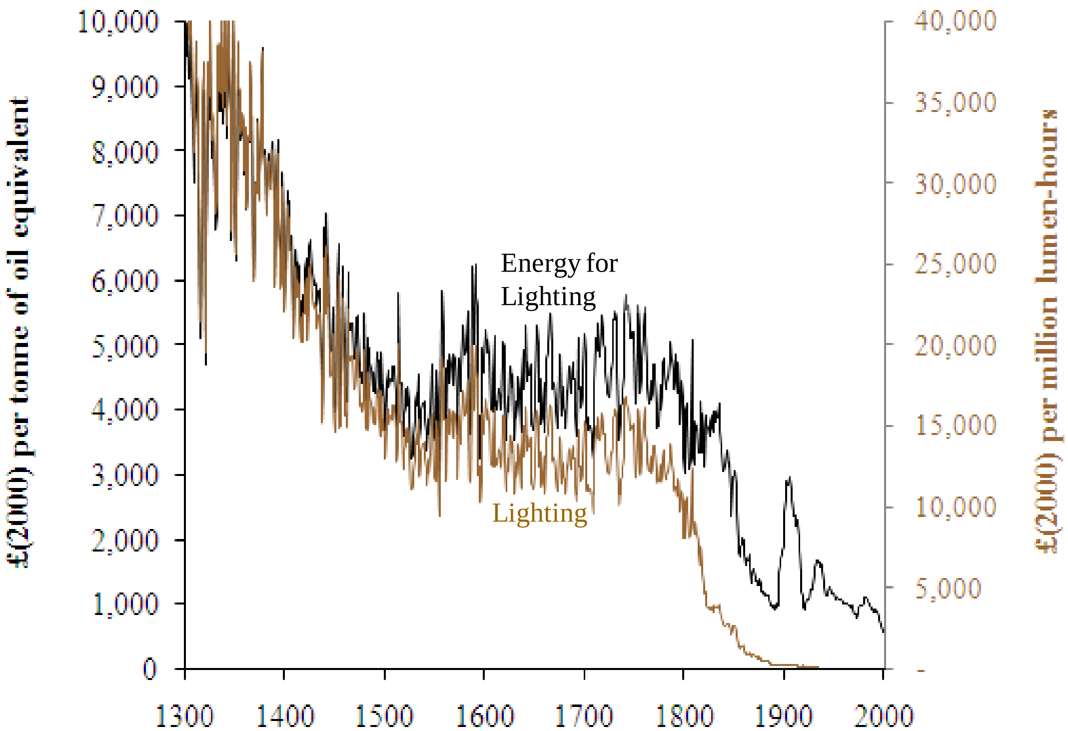
Evidence for passenger transport prices only starts from the beginning of the eighteenth century, and follows more closely the trend in the price of energy (see Figure 8). However, a similar divergence in prices appears in the mid-twentieth century and implies the same risk of using the wrong variables for analysing passenger transport services.

Figure 8. Prices of Energy (for Passenger Transport) and of Passenger Transport in the United Kingdom (1300-2000)



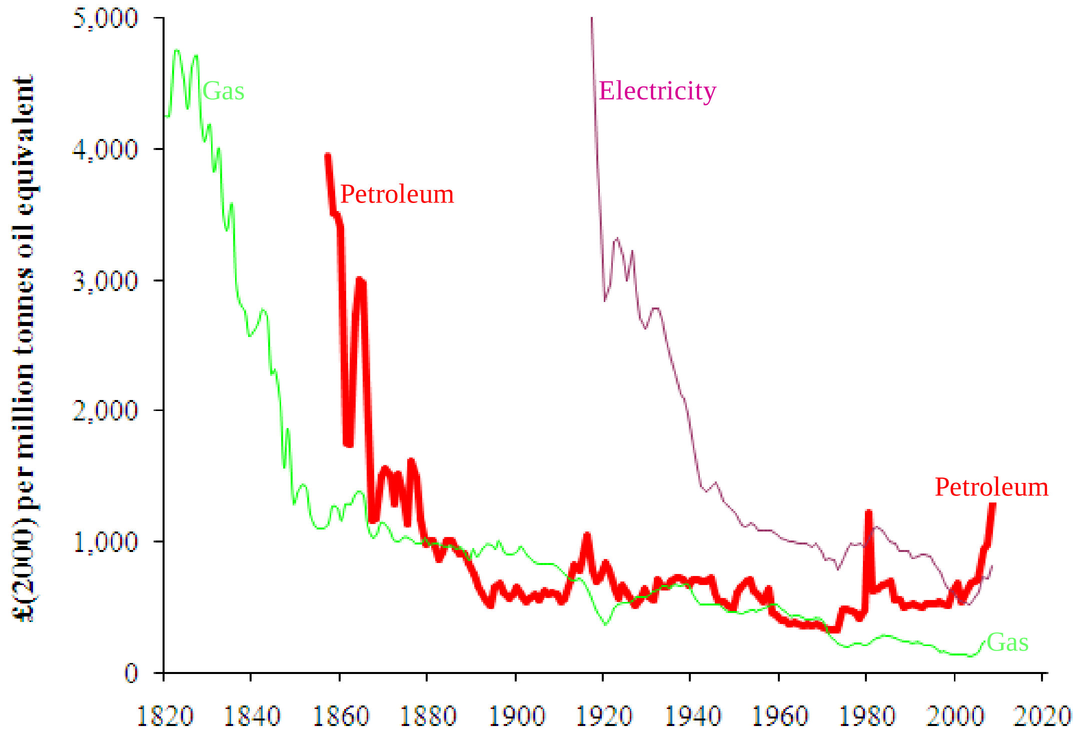
The price of energy for lighting fell rapidly from fourteenth to the sixteenth century, as the main source (tallow or animal fat) was in relatively large supply (see Figure 9, left axis). It then stabilised and rose a little, as the growth in demands were greater than the increase in supply. From the nineteenth century, new fuels (town gas, kerosene, and then electricity) were being used. In the beginning of the switch, in the 1820s, per unit of energy, town gas was more expensive than tallow candles (averaging more than £(2000)3,000 and about £(2000)2,000 per tonne of oil equivalent, respectively). Yet, town gas lighting technology was twice as efficient at converting the fuel into lighting as tallow candles. By 1850, town gas was half the price of tallow candles, per unit of energy, and far more efficient.

Figure 9. Prices of Energy (for Lighting) and of Lighting in the United Kingdom (1300-2000)



In 1900, when electricity began to replace town gas for lighting, it cost twenty-five times more per unit of energy (£(2000)10,000 and £(2000)390 per tonne of oil equivalent, respectively). At the time, electric lighting was seven times more efficient. So, at first, electric lighting was more expensive than gas lighting. Nevertheless, it was still used in luxury homes, restaurants and theatres, where novelty of the new technology was highly valued (Schivelbusch 1988). By 1930, when a rapid switch was occurring, electricity was still five times as expensive, but electric lighting ten times more efficient. Thus, despite rapid declines in the price of the new energy sources (see Figure 10), in the nineteenth and twentieth centuries, there was a shift to costlier fuels but cheaper lighting (right axis). The average price of energy for lighting hardly fell in the twentieth century despite rapid declines in the price of lighting and increases in consumption far greater than the efficiency improvements (Fouquet and Pearson 2006). To use energy prices as a guide to energy consumption would be again misleading.

Figure 10. Prices of 'New' Energy Sources in the United Kingdom (1820-2008)



6. The Average Price of Energy and of Energy Services

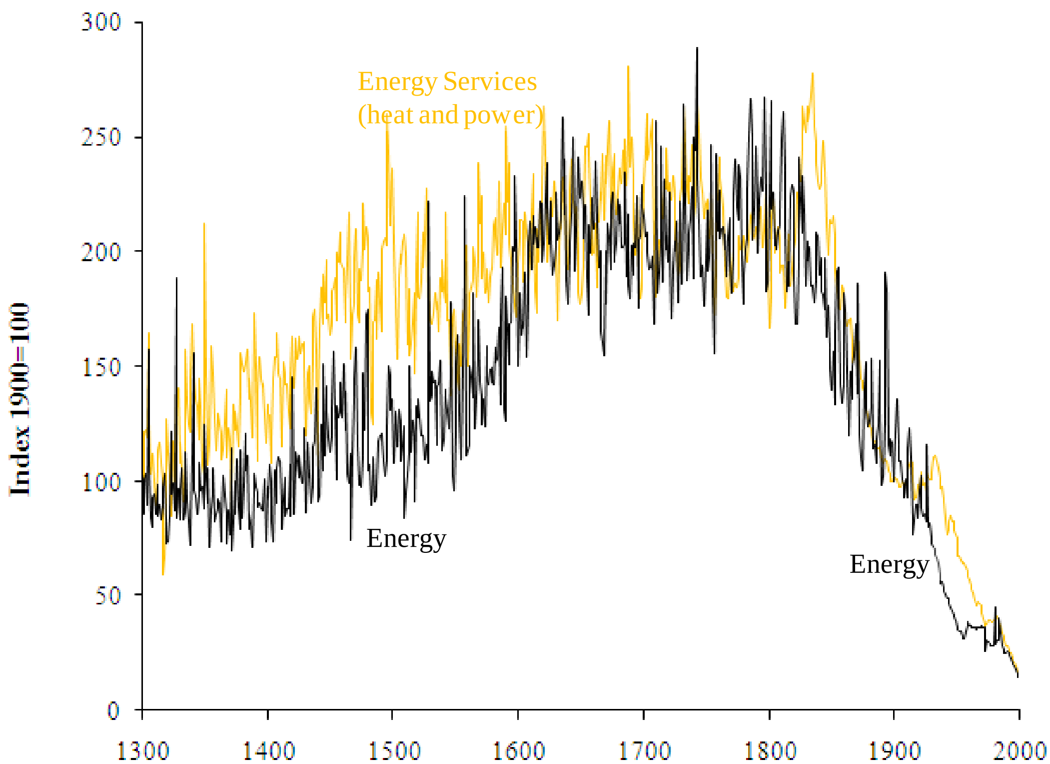
Given that energy is often discussed in its broadest terms, an average price of energy and of energy services can be interesting to examine and compare. They might also be compared with other goods or services.

Insufficient data on expenditure exists to complete full average price series back to 1300. Instead, the average price of energy and energy services associated with heat and power are presented (see Figure 11). Then, from 1700, when transport and lighting expenditures exist, the full average price of energy and related services can be examined (see Figure 12).

Over this very long period, the broad trends for energy and service prices are similar: a rising price for both energy and its services until the Industrial Revolution and then a declining one afterwards. This reflects the growing pressure on land, as the population and the economy were growing in the early modern era, and then the transition from renewable sources of energy to fossil fuels – woodfuels to coal for heating and food and fodder to coal for power. For heating and power services, there have been considerable improvements in energy efficiency since the Industrial Revolution.

This average series represents overwhelmingly the price of power until the end of the nineteenth century. Indeed, the peak between 1820 and 1835 reflected the higher real wage rate (resulting from deflationary pressures) and the rapid expansion of the population and the labour force (increasing the weight of relatively expensive humans). As late as 1850, power accounted for 80% of the heating and power expenditure; by 1900, this had fallen to 55%, as human and animal power was replaced by cheaper steam engines.

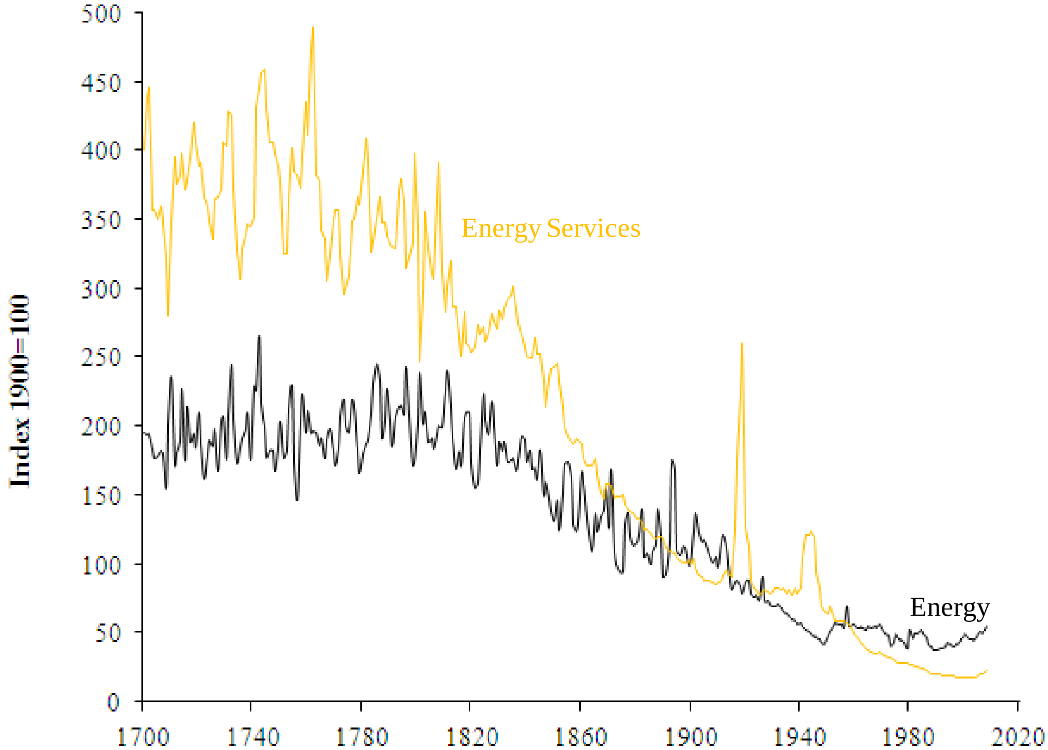
Figure 11. Average Price of Energy and of Energy Services (Heating and Power) in the United Kingdom (1300-2000)



Differences in the trends in the prices of energy and energy services are particularly apparent since the Industrial Revolution (see Figure 12). These other average price series incorporate transport and lighting, as well as heating and power. The differences are more apparent. From 1760 to 1913, the average price of energy services fell much faster than the price of energy. Between 1913 and 1950, the trends were reversed and the price of energy fell faster. Then, again, from 1950, prices of energy services dropped considerably, while energy prices remained (in a historical context) within a small range.

A couple of observations are worth making about events in the twentieth century. First, peaks in the average price of energy services are due to the high cost of sea freight transport during the two World Wars. Second, surprisingly, the average price of energy increased only slightly during the Oil Shocks of the 1970s. Heating was dependent on gas and power was driven by electricity generated mostly from coal; thus, the higher oil prices were muted by other fuel prices.

Figure 12. Average Price of Energy and of Energy Services in the United Kingdom (1700-2008)



7. A Comment on Current Trends in Energy Prices

Now, examining the most recent period, all energy prices have risen considerably since the beginning of the twenty-first century (see also Figure 10). Undoubtedly, global demand for energy services and, thus, energy has soared, as the Chinese economy in particular has expanded. Yet, placed in a historical context, it is clear that many peaks preceded the price hike of 2008.

Between the seventeenth and the nineteenth century, commentators anticipated coal prices to soar, with grave impacts on the economy. Temporary hikes were faced, but price trends, in the long run, stayed remarkably stable. Suppliers continued to deliver - finding new and deeper reserves, and hiring more workers to meet the demand.

In the 1920s, the new energy sources, petroleum and electricity, temporarily struggled to meet the rapidly increasing demand for personal transport, power and lighting. Prices peaked, and then the capacity of petroleum and electricity industry expanded to meet the new needs. Similarly, in the 1970s observers were expecting permanently higher energy prices. Yet, from the mid-1980s, nearly twenty years of low energy prices followed.

So, despite many peaks in the past, markets adjusted. Suppliers found new reserves and built greater infrastructure. Consumers, where possible, reduced wastage, increased efficiency and substituted to cheaper sources. And, long run trends in individual prices continued a relatively stable and slightly downward trend.

Thus, looking forward, and within this historical context, it is tempting to conclude that the trend in individual prices will be generally downwards, although peaks can be expected. The global recession is allowing energy producers and suppliers time to expand reserves and infrastructure - Iraqi and Brazilian oil fields may help; greater expansion of Russian and North African gas reserves will, no doubt, also assist. In 2010, another phase of scarcity has passed, as the global economy recovers from the recession, and a new period of relative abundance lies ahead – at least for a few years. This will help boost growth around the world, which will generate greater demand for services and energy. In turn, another phase of scarcity will ensue. It is tempting to expect, in the long run, cycles of scarcity and abundance, along a slightly downward trend (Fouquet 2008).

Might the current process of internalising the external costs of carbon alter matters? This process is a once-and-for-all shift. It seems appropriate to expect an upward shift in individual prices of energy, particularly sources with higher carbon contents. Both suppliers and consumers will adjust by favouring low carbon energy sources. This will in turn put downward pressure on high-carbon energy prices and upward pressure on low-carbon energy prices. Finally, all of this, it is tempting to conclude, will be within a backdrop of declining long run prices.

8. Declining and Diverging Trends

At this point, it is worth making some general observations and summarizing. First, since 1800, the overall trend in prices of energy and of energy services has been downwards (see Table 1). Average energy prices for heating and lighting were declining more gradually between the fourteenth and eighteenth centuries. A key aspect of the Industrial Revolution was the development or expansion of markets for a whole series of new energy sources, enabling substitution. This implies that even if individual fuel prices may rise in the long run (and there is limited evidence to support this for fossil fuels), average energy prices reflect the substitution between sources towards cheaper ones. Thus, in general, where resources are not limited by land availability and substitution is possible, we can expect average energy prices to trend downwards.

Table 1. X-Fold Decline in Prices of Energy and Energy Services (1800-2000)

	Price of Energy	Price of Service
Heating	0.7	7.4
Power	14.1	26.0
Transport (freight)	2.9	10.0
Transport (pass.)	2.9	9.1
Lighting	5.7	4,380
Average	**4.2**	**19**

Source: adapted from Fouquet (2008)

Second, the early experiences of power and transport show us, however, that the economy can suffer from long run rising prices of energy and services. Energy services that were dependent on horses before the diffusion of steam had rising prices up to 1800, reflecting the growing pressure on land and, thus, agricultural products and lack of large-scale substitutes. Without the switch to fossil fuels, the growth of the United Kingdom and most other economies would have been severely constrained and would have faced further increases in the average energy and service prices.

Third, it is interesting to consider the prices of energy for different services. Heating fuels have been very cheap – at least one-tenth of the price of energy for power and transport before the twentieth century. Historically, heating fuels were relatively abundant, either from wood or from coal, compared with say lighting sources, which depended on animals fats or vegetable oils. Also, generating heating fuels was a `simpler´ process (e.g. collecting or mining) than producing and preparing agricultural products (the 'fuels' of humans and animals) for power, transport and lighting services of the past. This difference in the cost of energy sources has no doubt pushed the economy towards using energy for heating purposes, such as the transformation of metals and other materials. Also, this favoured the development of an economy driven by heating to generate power (i.e. fossil fuel-based electricity), transport (i.e. the internal combustion engine) and indirectly lighting (i.e. electricity).

But, energy prices to the consumer vary for a number of reasons. Extraction and production costs are obviously important. They reflect, to some extent, the scarcity of resources and the production process. But, prices can also change due to distribution costs, market structure and taxes. Finally, prices can vary because consumers place a different value on certain energy sources. Indeed, the price at any time indicates that consumer´s willingness to pay for an additional unit of energy. The relative abundance and production process of heating fuels had enabled consumers to generate heat until the marginal utility and willingness to pay was relatively low.

Conversely, the price of energy for lighting (per tonne of oil equivalent, i.e. unit of energy) has been consistently higher than for other energy services. This no doubt reflected both scarcity and other production costs. Historically, the production of illumination fuels was probably the most `complicated´ process since, in the United Kingdom, it was mostly dependent on animals fats. The scarcity of lighting sources and the more complex process implied less consumption and more careful rationing. Consequently, in 1800, for instance, based on evidence from different energy prices, the marginal utility from consuming an additional (equivalent) tonne of energy for lighting (or even power or transport) was greater than for heating.

At the beginning of the twenty-first century, the price of the main energy sources, whether natural gas, oil or electricity, which are used for heating, transport, and power and lighting, respectively, are far closer than energy prices historically. These trends suggest that today the marginal utilities of consumption of energies for different services have also converged.

Yet, drawing conclusions about marginal utility based on price data ignores that, over time, the ability to generate services with each unit of services has increased. With a more efficient technology, a source can generate more services per unit of energy – so, it is more valued (than a source that would be used with less efficient technology). As efficiency increases, consumer value for the energy source can be expected to rise. The introduction of more 'efficient' heating fuels at the end of the nineteenth century implied a higher value associated with the new fuels. On the other hand, as consumers use more services, their marginal utility of each unit of service is likely to fall. Whether it falls below the willingness to pay for the initial energy source depends on which is greater the rise in efficiency or the decline in marginal utility. Thus, after the introduction of new sources or technologies, consumer willingness to pay should initially rise and then fall. And, these fluctuations in value may be seen in energy prices, and should not be confused for signs of increasing scarcity.

Fourth, interestingly, the major divergence between the trend in the price of energy for lighting and of lighting (first presented by William Nordhaus (1997)) was the most dramatic of all the energy services (see Figure 9 and Table 1). Since 1800, the price of lighting in the United Kingdom fell 770 times more than the price of energy for lighting. The high price of and willingness to pay for lighting sources certainly called for a need to find technical solutions and, at the end of the eighteenth century and early nineteenth century, great efforts were put into improving lighting fuels and technologies.

Yet, despite its relative affordability, the price of heating fell far more than the price of its fuels (10 times more) – and more than for power (which fell twice as much as its fuel prices). Of course, an economy dependent on heating would also benefit greatly from better technical efficiency. Yet, it also reminds us that the evolution of the price of energy and its services reflects physical, as well as economic, factors, which economist are not in a position to explain.

9. Conclusion

The purpose of this paper was to present evidence on the trends in the prices of energy and of energy services from the fourteenth century to the present day, in what is now the United Kingdom, and the divergences between the two.

The broad trend (over the last seven hundred years) in prices associated with energy and their services was first upwards, as the expanding economy faced increasing pressures from consuming mostly limited renewable energy resources, and then downwards, as fossil fuels replaced them. The downward trend (over the last two hundred years) suggests that, in the eyes of the market (and despite some commentators concerns), energy resources were perceived to be `unlimited´. An important aspect of energy markets has been the ability to find new resources, to substitute between sources as prices rose, and to introduce more efficient technologies in production, distribution and consumption.

The very broad trends in the prices of energy and energy services are similar (upwards then downwards). However, especially since the Industrial Revolution, trends have diverged. The last two hundred years has been a period of exceptional technological innovation in history. The cost of generating services has changed greatly as a result of the ability to use resources more efficiently, rather than just from the price of the resource. Indeed, this can be a source of additional divergence – in the case of heating, while the price of the service was falling due to greater efficiency of new fuels, the average energy price for heating was rising because consumers placed a higher value on the new fuels. Consequently, focussing exclusively on the long run trend in energy prices might lead to misleading conclusions.

So, in the long run, the price of energy and the price of energy services diverge significantly. Yet, mostly because of the lack of data, economists still use commodity price series rather than those for services. It may also be due to a lack of appreciation of the implication of not using them.

The divergences between the trends in the price of energy and of related services have major implications for the process of studying long run trends in energy markets and climate change. Nordhaus (1997) pointed out how focussing of energy prices in the long run dramatically underestimates the welfare gains to the consumer. This paper shows that in the long run, people have also been able to heat their homes, push and pull objects, and move people and goods, as well as light their homes, far more cheaply. This has radically altered people's lives – far more than the standard analysis would indicate. Also, a study might conclude, for instance, that consumers are facing much higher prices at the beginning of the twenty-first century, when they are actually experiencing only slightly more expensive services, thanks to efficiency improvements.

Modellers need to try to estimate income and price elasticity of the demand for heat, power, transport and light, as these drive behaviour associated with energy consumption and greenhouse gas emissions. Focussing on energy rather than energy services will lead to misleading estimates of consumer responses to long run income, price and efficiency changes.

The devil´s advocate could argue that the inclusion of energy services helps little. This argument will be countered with two extreme examples by showing that although these examples appear to ignore services, they are actually making assumptions about them. The `efficiency optimist´ might suggest that if energy efficiency improves by 10%, energy consumption will fall by 10%. The `laggard economist´ might propose that since the price of energy is unchanged consumption of energy will remain unchanged. Both stances are conclusions from analysts who ignore the importance of energy services. By ignoring them, they are both making an implicit assumption about the price elasticity of demand for energy services.

Since the efficiency has improved by 10%, the consumer can generate the same quantity of the service with 10% less energy. This implies that the price of the energy service has fallen 10%. For energy consumption to fall by 10%, energy service use must remain unchanged. So, the `efficiency optimist´ assumes that the price elasticity of demand for energy services is zero.

Again, in the case of the `laggard economist´, the consumer can produce 10% more of the service with the same amount of energy from the 10% efficiency improvement. This implies that the price of this energy service has fallen 10%. For energy consumption to remain unchanged, energy service use must increase 10%. So, the `laggard economist´ assumes that the price elasticity of demand for energy services is one.

The literature on the rebound effect is arguing (often, implicitly) that the price elasticity of demand for energy service cannot be assumed to be zero or one. The size of the price elasticity is an empirical question. Given the importance of understanding long run energy behaviour, economist need to start studying and (however crudely) estimate the price and income elasticities of demand for energy services.

Models of energy consumption and forecasts of greenhouse gas emissions are often based on the relationship between energy use, GDP growth, and fuel prices. Because of the lack of data and possibly the lack of awareness about the implications, energy service demand has been ignored. But better insights about future fuel use and emissions might come from understanding the two-stage relationships between: (i) energy use, energy technologies and delivered energy services; (ii) and between energy service consumption, GDP growth and the costs and prices of energy services. Inclusion of energy services in models should improve our understanding of energy markets both in industrialised and developing economies (Modi 2004). This is especially true in the twenty-first century, when great efforts are being made to develop new efficient energy technologies and to anticipate future greenhouse gas emissions.

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