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Jevons' coal question: Why the UK Coal Peak wasn't as bad as expected

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In his book The Coal Question from 1865, William Stanley Jevons examined for how long the United Kingdom could continue to fuel its economy based on cheap supplies of coal. At the time the UK consumed about 93 million tons of coal, providing nearly all of its energy supply. His estimate was that within a maximum of a hundred years, or perhaps even within one or two generations, production would be in retreat due to an increase in the cost of mining which would, in Jevons' words, "Injure the commercial and manufacturing supremacy of England."

In this post I'll look back at history to show that Jevons correctly foresaw the fate of the British coal industry. In Britain a peak in production occurred around 1913 caused by increasing coal mining costs, lack of technological innovation, rising competition from abroad, a number of political decisions disadvantaging coal as a fuel source, declining profits, and a slump in British economic growth coinciding with World War I. Although geology had an important role to play in determining the cost of coal, it was not the overarching factor that led to the decline in British coal production. Fortunately for Britain, Jevons was too pessimistic about the economic consequences. He did not foresee both the adaptation of the British economy in reaching higher overall efficiency in a high energy price environment, and the eventual large scale introduction of petroleum.

Jevons' analysis on British coal supplies

The analysis carried out by Jevons hinged upon two thoughts. First, he assumed that the consumption of coal would continue at a pace of 3.5% per year extrapolated from previous decades. Second, he expected that prices would become too high as mining progressed beyond 2,000 feet towards 4,000 feet of depth. From his calculations he found that an average mining depth of 2,000 feet would more than double the price of coal and that a further doubling could not be borne by the industry.

In his assessment he made the following astute observations that are still qualitatively valid for resource assessments today:

• *"And, of course, when Mr. Vivian asserts that South Wales can supply all England for 500 years, he means at the present rate of consumption, which is quite beside the question. The question [of resource depletion] is, how long will South Wales supply us at the present price with the present growing demand?"*

• *"The higher the price rises, the more thoroughly will the coal-measures be worked, and the more coal becomes workable. As, however, the high price of coal constitutes the evil of exhaustion, the dreaded results are only somewhat mitigated, not prevented. And it would be wholly erroneous to suppose that when once the thicker seams of a coal district have been worked out, we can readily, at a future time, work out the thinner seams, when the increased price of coal warrants it"*

• *"All then that we can hope from thin seams, or abandoned coal, is a retardation of the rise of price after a considerable rise has already taken place. This will hardly prevent the evils apprehended from exhaustion... If seams of 18 inches are now occasionally workable, the coal-cutting machine may reduce the limit a few inches; but it is evident that seams of less than 12 inches could never be worked while the price of coal remained at all tolerable."*

• *"When the general depth of coal workings has increased to 2,000 feet, little or no coal will be sold for less than 10s. per ton, and the choice large coal will have risen to a much higher price. Our iron and general manufacturing industries will have to contend with a nearly double cost of fuel. And when with the growth of our trade and the course of time our mines inevitably reach a depth of 3,000 or 4,000 feet, the increasing cost of fuel will be an incalculable obstacle to our further progress."*

British coal production and consumption

The development of British coal production, shown in figure 1 below, clearly shows production hit maximum in 1913, thereafter declining by around 2% per year on average until the late 1940s. The brief bump in production from 1947 until 1957 was caused by a nationalization of the coal industry. The government injected large sums of money into the sector in an attempt to revive it. The government's production targets were not reached however, and competition by the market made the effort unsuccessful. Subsequently, most of the government's subsidies were abandoned in the 1960s. Market forces resulted in a rapid rise of oil imports fuelling domestic consumption for both transport and electricity production. After the discovery of oil off the Scottish coast in the 1970s there was even less economic incentive for coal mining. There was and is still a lot of coal remaining in the United Kingdom, but it has at least until present been too costly to get it out of the ground.

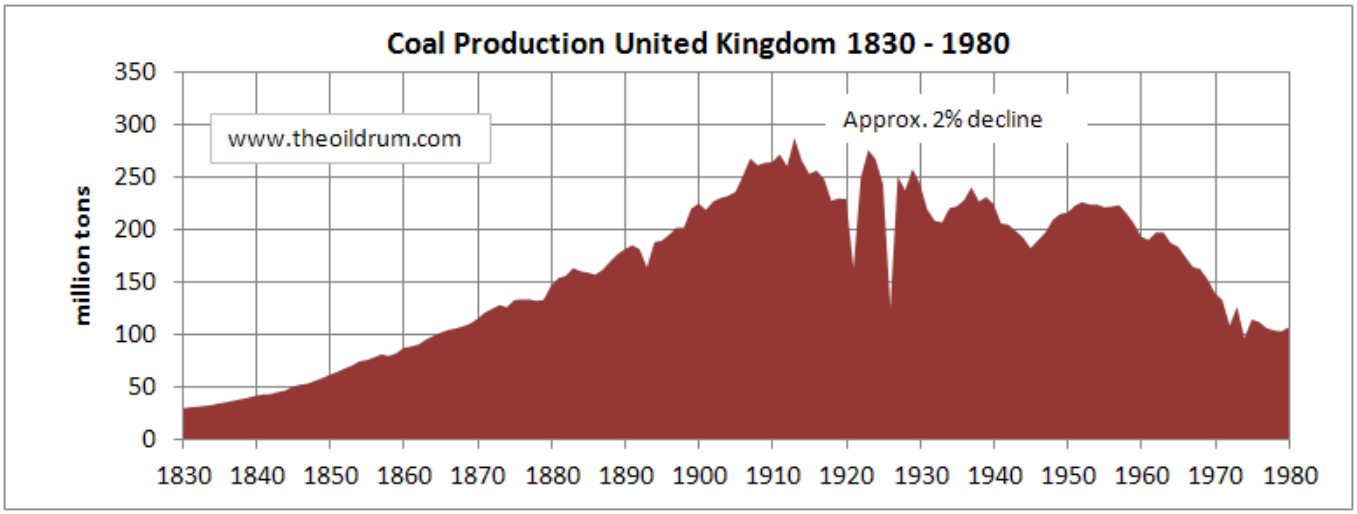

Figure 1 – British Coal Production 1830 - 1980. Source of data: Mitchell (1988)

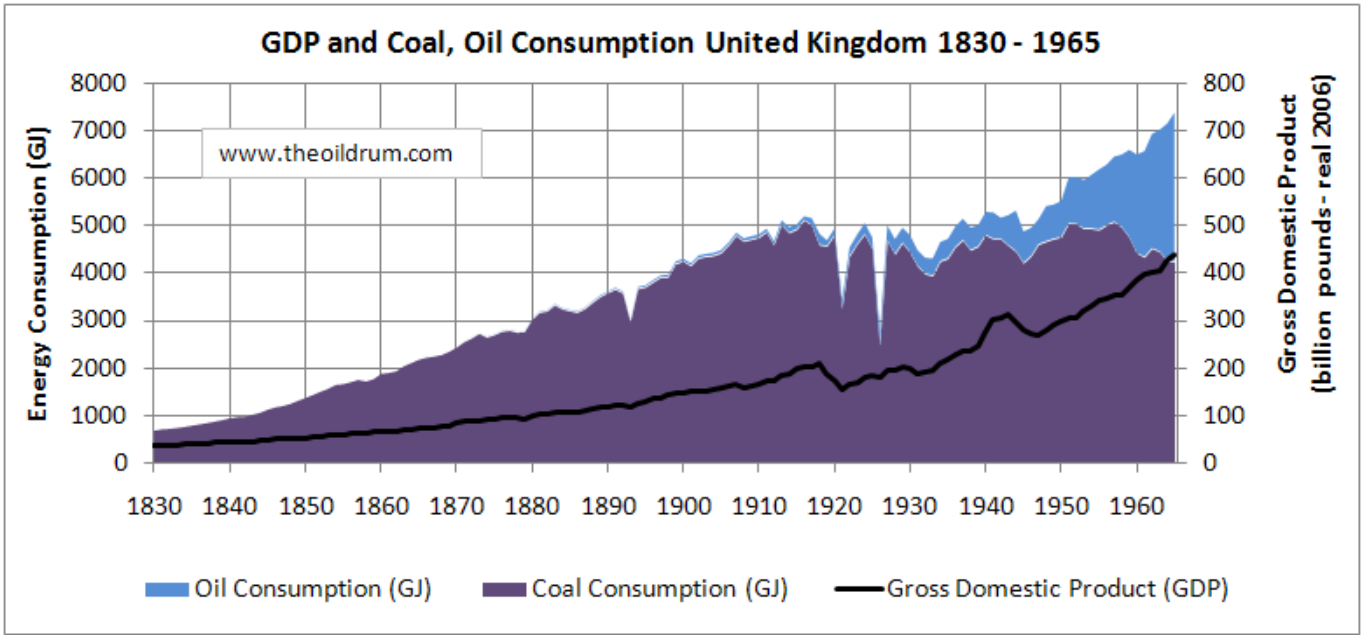

Figure 2 – British Coal and Oil Consumption and GDP 1830 - 1965. Source of data: Mitchell (1988), Ryland et al. (2010)

Many authors have concluded that the fairly fuzzy peak in British coal production and other coal nations occurred for geological reasons, inferring that coal will behave the same as conventional oil does. Based on this expectation, logistic or Hubbert type models are applied to model "peak coal" in other regions and the world. For example, in figure 3 below from Hook et al (2010), a logistic fit is given to the coal production of three different countries. This approximation mainly based on geology appears to fit well but it is rough, and gives little insights in advance to what will happen, unless you know in advance how much coal will be extracted, which is precisely what is unknown as most countries data is quite poor. In other words, this curve fitting approach gives little information about how economic conditions will influence the amount of extractable coal, and, because of this, we are still in the dark about how production will really progress. Peak coal production forecasts based on present technology range from now until around mid century, depending on uncertain reserve and resource assumptions, as shown by Mohr and Evans (2009). Even more uncertainty is added when technology which is not yet commercial is included, such as underground coal gasification, and its use on offshore coal, as discussed in my previous post on underground coal gasification. These types of advances could lead to an expansion of the coal era.

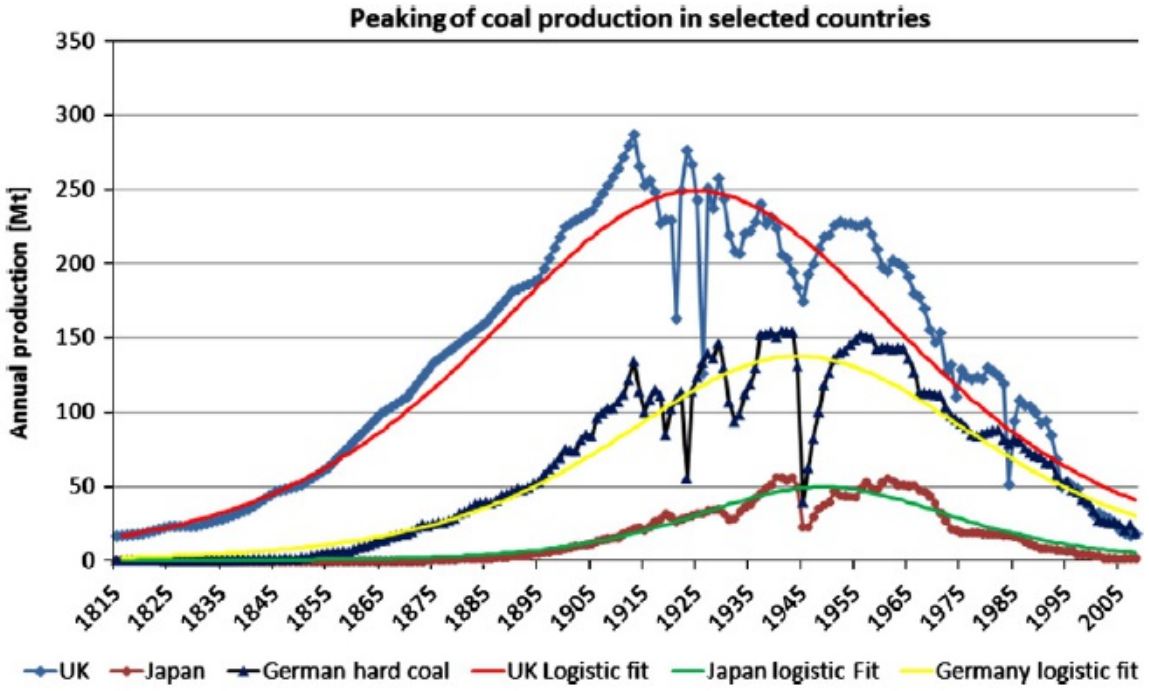

Figure 3 - Logistic fit to UK, Germany, and Japanese coal production. Source of figure: Hook et al. (2010).

Looking at coal production from a productivity perspective

In the absence of good data, it is helpful to utilize a range of methodologies, and that is where we can learn a great deal from Jevons. He did not care precisely when coal would hit its peak as his concern was that a point would come when Britain no longer could afford to increase its extraction rate. To ascertain this he looked at geological combined with economic data. The same approach is valid today. We could look at the costs of each coal producing region and look at what we can afford to get out of the ground. How many labour hours, energy, mineral resources, and machines do we need to obtain a lump of coal? Can we afford to utilize so many resources for those purposes? Only few analyses are available in this regard, one of which was made in 2009 for Gilette the largest coal field in the United States.

To show that Jevons' methodology made a great deal of sense, I compare a number of statistics. First, in figure 4 below, the production and consumption of coal in the United Kingdom is shown, the difference being caused by exports to mainly the European mainland. The data shows that

consumption of coal peaked a little bit later than production as the end of World War I neared. After the war, the British economy declined for a number of years after which growth returned with occasional one to two-year recessionary bumps until the second world war, which similar to the first, coincided with a substantial economic decline. No increase in coal consumption fuelled the inter-war expansion, however, plausibly due to an earlier oversupply, the switch from coal to oil of the British navy after World War I, and an increase in efficiency of British manufacturing and household energy use. Singer (1941) states that:

> "We conclude that over the eleven years from 1924 to 1935 the increase in the efficiency of the use of coal- which must in these cases be attributed to direct economy - led to a fall in relative coal consumption by some 38 million tons or 28 per cent of what total industrial consumption would otherwise have been. This is equivalent to a fall, through direct economy and substitution, of 3.0 per cent per annum. It is clear that the 1924-35 period must have played a leading part in the relative fall in coal consumption, which was at the rate of 33 per cent in the last twenty-five years (Singer 1941, p. 170)."

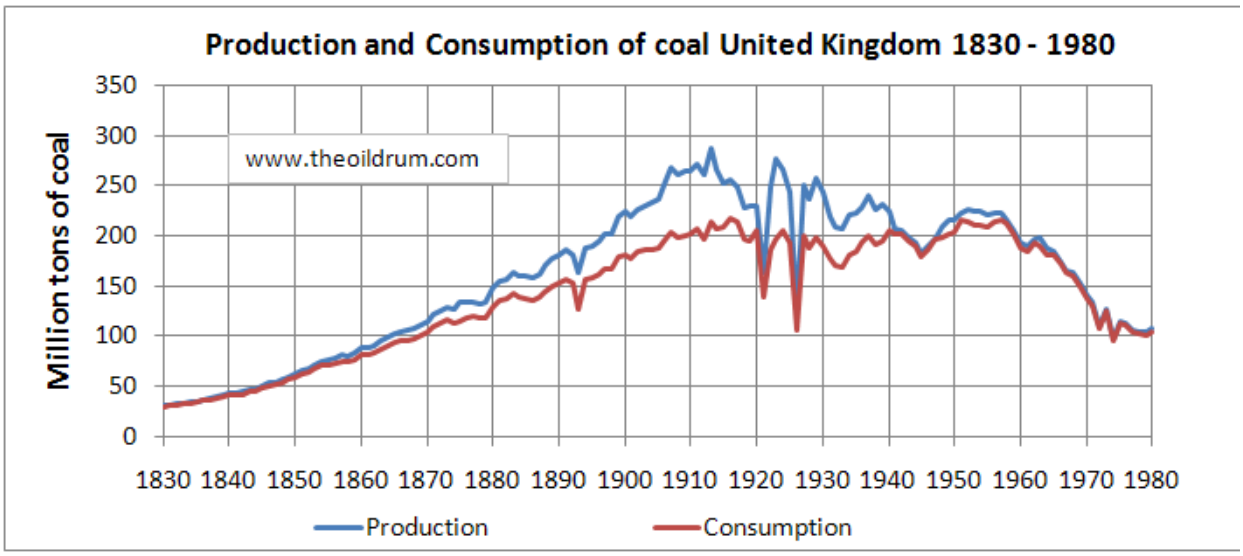

Figure 4 – Production and Consumption of coal in the United Kingdom 1830 - 1980. Source of data: Mitchell (1988)

The absence of a domestic need to substantially increase coal supplies coincided with reduced demand for coal exports because of competition from other regions. One region that was especially important in the decline of British exports was the German Ruhr area, where there was an increase in coal production at lower cost due to greater productivity. In addition due to post World War I reparations under the Dawes Plan, Germany would export coal for free to France and Italy as a form of repayment of war damage, at a large disadvantage to Britain. As a result, by the late 1930s, Britain ceased to be a meaningful exporter of coal. Thus the decline in British coal production after 1913 reflected a combination of factors, including both reduced internal demand (from both recession following World War I and from increased efficiency) and reduced demand for exports. If circumstances had been different (for example, greater technological innovation in British coal mining), the peak in British coal production would probably have been postponed substantially.

The increase in British coal production since the 1860s, the time of the Jevons coal question, was not caused by an increase in productivity but by employing more labour in the industry. From 1865 until 1913, the mumber of people working in coal mines rose by a factor of 3.5 from 315.000 to 1.13 million people, shown in figure 5. Roughly 2.5% of the population was employed in 1913 to haul coal out of the ground and cut it into usable pieces. In the same period productivity declined from around 0.14 to 0.11 tons of coal mined per hour of labour, shown in figure 6. The reason of the decline in amount of coal mined per hour can be explained from the absence of technological innovation combined with the need to mine increasingly deeper and thinner seams as foreseen by

Jevons. About this issue Taylor (1961) remarks:

> "...by the 1880's in all but the smallest collieries the steam-engine was in use both above and below ground and its benefits were being felt throughout every coalfield. By comparison with this earlier period the years between 1880 and 1914 have less to show in terms of technological achievement. Improvements were constantly effected in shaft and underground haulage and steam-power gradually gave place to electricity, but none of these changes was by nature or consequence of a revolutionary character. Potentially the most far-reaching innovations of these years were those affecting work at and near the face - involving the introduction of the coal-cutter and the conveyor - but progress in these directions was very limited. As a workable mechanical novelty the coal-cutter was already in existence before 1880, yet as late as 1913 only 8.5% of British coal was mechanically cut and an even smaller proportion was mechanically conveyed (Taylor 1961, p. 59)."

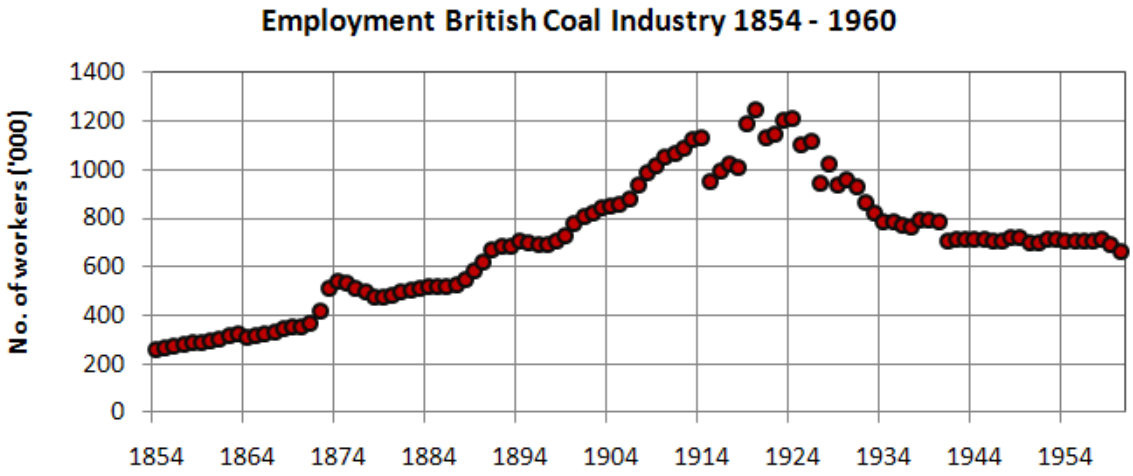

Figure 5 – Employment in the British Coal Industry from 1854 - 1960. Source of data: Mitchell (1988)

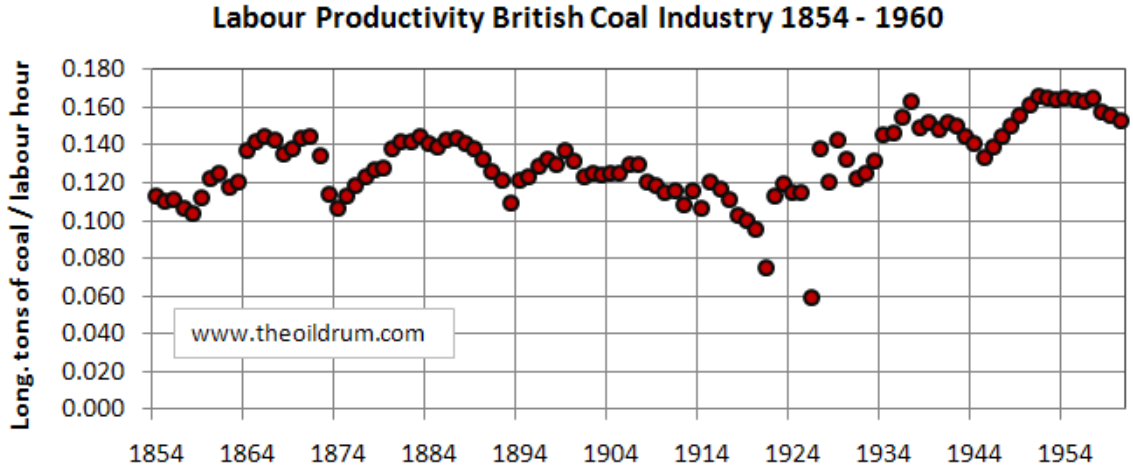

Figure 6 – Labour Productivity in the British Coal Industry from 1854 - 1960. Data calculated based on: Mitchell (1988), Greasley (1990)

The peak hence occurred because the number of employees could not rise sufficiently as productivity declined. This was aggravated by the temporary loss of employees that were drafted

into the army during the first world war, as clearly shown in figure 5. The inability to attract new employees occurred because British mines could not afford to pay a competitive wage and, at the same time, keep the cost of the coal they sold competitive on the international market. British coal prices increased to unseen heights, as shown in figure 7, and the country could no longer compete with coal producers abroad. Data shows that after 1910 British productivity on average was overtaken by Germany, by 1925 it was 6.8% higher, and by 1935 Germany produced 23.6% more coal than Britain in terms of labour output per hour (Broadberry 1998). The coal in Britain became too expensive versus that in other markets and exports dropped.

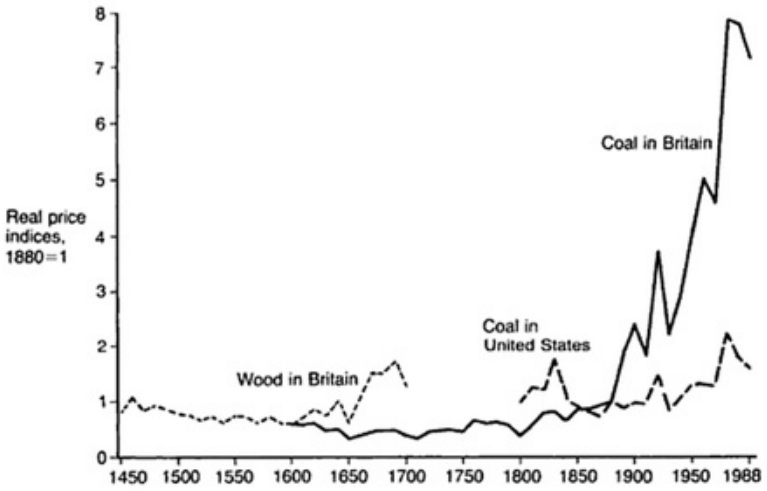

Figure 7 – The price of British coal from 1450 to 1988. Source: Hausman (1995)

The lack of proper wages in the face of rising costs of living was so severe that most of the coal industry went on strike in 1921 and 1926, resulting in losses of output of respectively 30% and 50%. The economic situation is described well in Wynne (1913):

> "The consequence is that the proceeds of a given output of coal which before the war supported six men had in 1925 to provide a living for seven. The price of coal in the market had not meanwhile risen to the same extent as wage costs per unit of output, and in the period September, 1924, to March, 1925, over 41 per cent of the total output of the British mines was raised at a loss. By May, 1925, this figure had risen to nearly 67 per cent, and during the last quarter of 1925, to 73 per cent, the loss ranging in this latter period from an average of only 2 pennies a ton in the eastern division to 3 shillings and 2 pennies per ton in South Wales and Monmouth, with an average of is 5 pennies a ton for the country as a whole. (Wynne 1913, p. 356-366)"

Earlier in 1919, the work day had already been reduced from 8 to 7 hours underground under increasing pressure by coal unions, further decreasing the amount of output the coal industry could potentially sustain. This caused a further decline in productivity versus other coal producers whose work day was slightly longer than the British. The only option left to solve the imminent situation was to close a large number of unproductive mining areas, raise the wages, and thereby further the decline in production during the 1920s. The move resulted in a rise in productivity, shown in figure 6, but it was too late. Britain as discussed by Taylor (1961) had already fallen behind other producers in implementing the technological innovations, which further contributed to the downfall of the British coal industry. The reason was the conservative nature of the British industry:

> "Electricity was looked upon with mistrust by many mines-inspectors until the Home Office Departmental Committee of 1904 expressed opinions favourable alike to its efficiency and to its safety when properly employed; but stringent safety regulations, as

> well as the conservatism of British mine owners and engineers, retarded the employment of electricity in British mines when it was already widely used in the coalfields of Germany and Belgium. Moreover, as in the use of machinery, the explanation of the shortcomings of British mining lay outside the industry as well as within it. 'Manufacturing electrical firms', it was said, 'do not care for colliery work in this country. They are able to obtain plenty of work in other directions' (Taylor 1961, p. 59)."

Britain missed the boat and began innovating at too late a date. The rise in productivity since the 1920s, as depicted in figure 6, could do no more than keep production declines at bay. The absence of substantial technological achievements, the increasing cost of coal production, and the rising competition from abroad led to a substantial drop in coal production.

The result of Jevons' publication

Since history unfolded more or less as Jevons expected it, at least for coal, we now know his study had little effect on altering the UK's energy future. Interestingly the coal question was taken seriously quite soon after publication. As a result of Jevons' book, Gladstone, the chancellor of the Exchequer at the time and later prime minister of Britain, commanded a royal commission to examine the coal question in depth and rigour in 1866. The report of the commission took five years to complete and was presented as a three volume work to both houses of Parliament and the Queen of Britain. Its conclusion confirmed the analysis of Jevons, but disagreed with one important point, the extrapolation of past coal consumption:

> "The results as summed up in the report to the Queen strikingly confirm the soundness of most of the conclusions arrived at by Professor Jevons, except so far as regards his estimate of the duration of the coal supply. Which, having in view the rapid increase of consumption which had continued up to that time, and the growth of consumption in relation to the increase of population, led him to believe that the total available supply of coal to a depth of 4,000 feet would be practically worked out in the short space of about one hundred and ten years. The author of this paper, however, when consulted by the omission, was of the opinion that the rapid and constant rate of increase assumed by Professor Jevons could not be maintained, "and that the very rapid increase in the annual production of which had hitherto occurred was merely a consequence of the equally rapid and abnormal development of our commercial activity which had followed the introduction of steam power in this country, and that the effect of this initial increase in the annual yield of coal is still perceptible, just as it is in a minor degree in the present rate of increase of our population. (Price-Williams 1889, p.2)"

The remark of the commission has been proven correct afterwards. Coal consumption increase tapered off as of the 1880s, shown in figure 8, and coal consumption per unit of economic output increased more slowly as large efficiency improvements took place in the early 20th century as shown by Singer (1941).

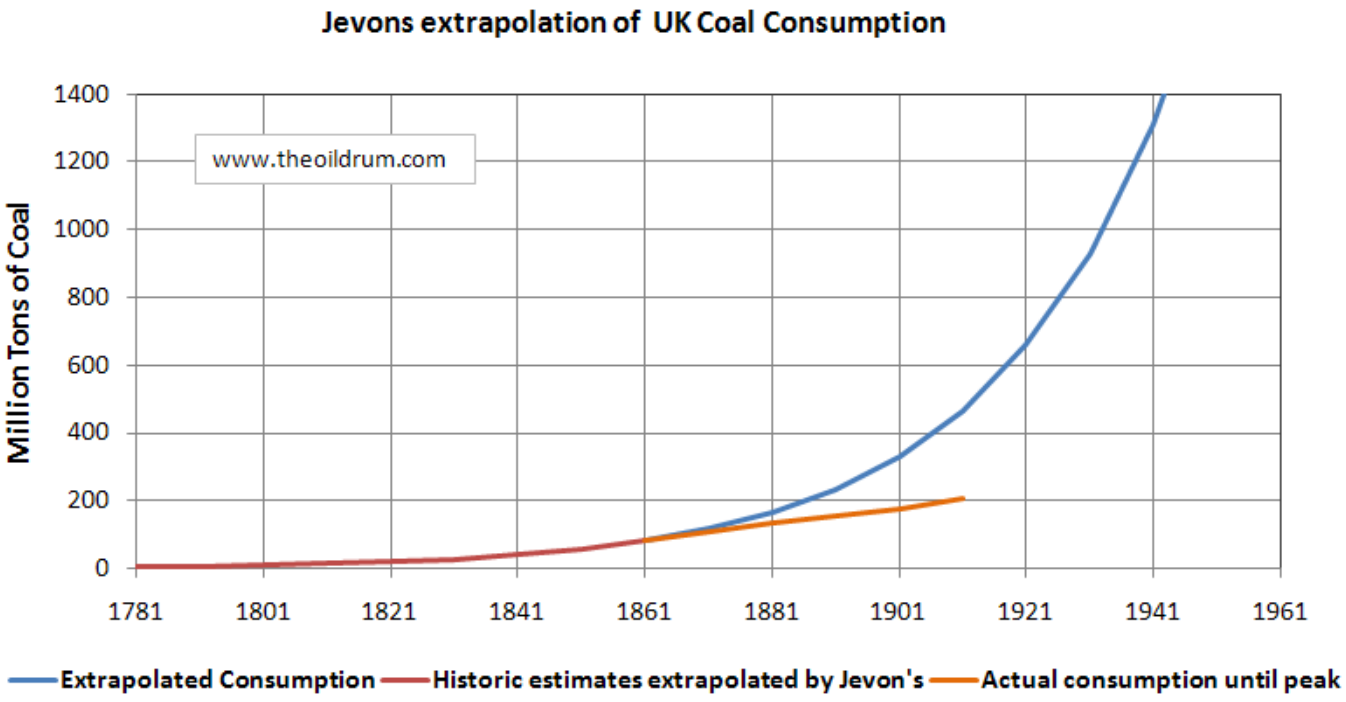

Figure 8 - Jevons extrapolation of UK coal consumption compared with actual consumption until 1911. Source of data: Jevons (1865), Mitchell (1988)

Also, Jevons was too pessimistic about the eventual development of petroleum, which in 1865 was only at its infancy:

> "Petroleum has of late years become the matter of a most extensive trade, and has even been proposed by American inventors for use in marine steam-engine boilers. It is undoubtedly superior to coal for many purposes, and is capable of replacing it. But then, What is Petroleum but the Essence of Coal, distilled from it by terrestrial or artificial heat? Its natural supply is far more limited and uncertain than that of coal, its price is about 15l. per ton already, and an artificial supply can only be had by the distillation of some kind of coal at considerable cost. To extend the use of petroleum, then, is only a new way of pushing the consumption of coal. It is more likely to be an aggravation of the drain than a remedy (Jevon 1865, VIII.42)."

Fortunately, for the United Kingdom, Jevons proved to be wrong in the effect of the decline in coal production on the British economy. Although the country lost its role as an industrial center, Britain has generally remained prosperous. Jevons expected otherwise: *"We cannot long maintain our present rate of increase of consumption...this only means that the check to our progress must become perceptible within a century from the present time (Jevons 1865, XII.29)."*

This doesn't mean that he won't be correct in the eventual outcome, however, as the oil and natural gas that replaced coal are both running in short supply with UK's peak production past us. We can replace the word coal with fossil fuels, and Jevons' words unfortunately could ring true today: *"the absolute amount of [fossil fuels] in the country rather affects the height to which we shall rise than the time for which we shall enjoy the happy prosperity of progress (XII.29)"*, unless we can find a new source of energy, or a way to transition to a happy life with far lower energy consumption and economic output.

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