The Industrial Revolution and British Economic Expansion in Relation to Energy Prices and Labour Costs

by

Sasan Fouladirad

Essay submitted to the
Department of Economics
As a requirement of the M.A. Economics program

Queen's University
Kingston, Ontario, Canada
June 2017

Acknowledgments

I feel extremely grateful to have Professor Taylor Jaworski as my supervisor. Having taken a course with Taylor Jaworski also allowed me to learn more about economic history, which I have integrated in my paper as well. Therefore, I would like to thank Taylor Jaworski for all his help, advice and feedbacks this year and hope to work with him again in the future.

I would like to thank Professor Sumon Majumdar and Dr. Antoine Djogbenou as well for all their support throughout the year and also, I would like to thank the Queen's Economics Department itself for giving me a wonderful experience throughout this program.

All errors are my own.

Dedication

To my wonderful parents, for everything that I am is because of them.

To my brother for his kindness and belief in me.

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Introduction

Looking back at the Industrial Revolution and examining it on a fundamental level, one vital question to ask is, why did the Industrial Revolution occur in Britain originally? Why for example it did not happen in a country such as France or Holland or other major countries in the world during that time period? This paper attempts to answer this question by looking at the foundations of Britain's economy before the Industrial Revolution with a focus on labour costs (or wages) and energy prices (specifically coal) and their relationship with industrial output. The works of Allen in *The British Industrial Revolution in Global Perspective* (2009) and Mokyr in *Lever of Riches* (1990) will also be analyzed as well since they have given answers to the same question, which is why Industrial Revolution occurred in Britain originally although each with different types of analysis and viewpoints.

In the first part of this paper, using combination of collected data from different sources, four regressions are run based on each sector of the economy (agriculture, industrial, services then real GDP) as the dependent variable and we will examine the correlation and significance of wages, energy prices, literacy rates and population on these variables. Works of Allen and Mokyr and their analysis on the British economy and Industrial Revolution will then be compared with the results and we will see if there are signs of consistencies. We will also look at examples of major British inventions (both macro and micro inventions) while analyzing the status and structure of the British economy during the Industrial Revolution and seeing how it was set up in favour of inventors and engineers to come up with new technologies and machineries.

In the second part of the paper, a cointegration test will be done using nominal wages (wages that people actually received), coal prices and industrial output as the variables and

we will see if there is a significant relationship between these variables from the year 1582 to 1815 and compare the results with analysis of Allen (2009) who came up with a similar model.

Section 1
Comparison and Analysis of Britain and its Economic Structure

1.0 Wage Levels and Energy Costs

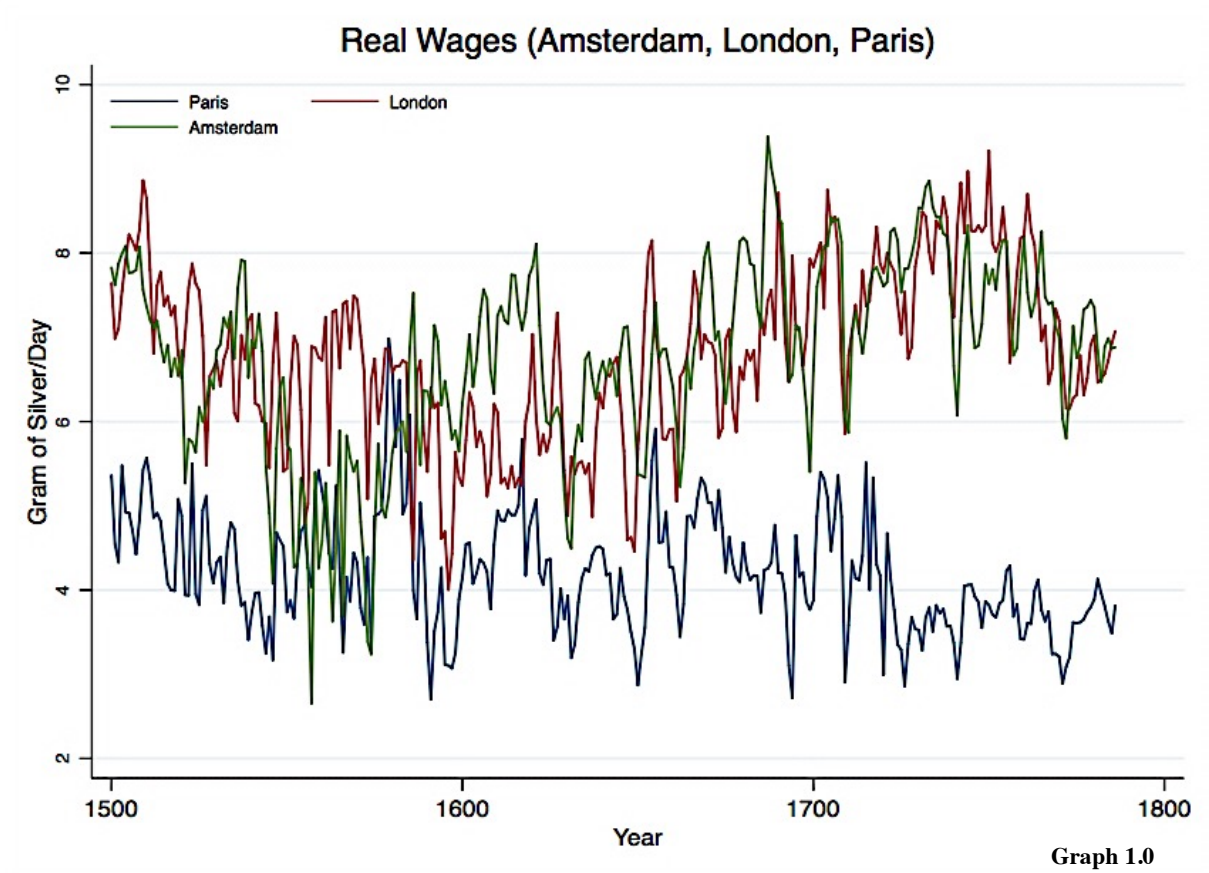
The data used in this paper is based on combination of data previously gathered by Allen, Broadberry, Campbell, Klein, Overton and Leeuwen. Data for wages (both nominal and real) and prices of energy for London, Amsterdam and Paris were collected from Allen while the data for agricultural, industrial and services output and GDP (real and nominal) were collected from Broadberry, Campbell, Klein, Overton and Leeuwen.

Based on the collected the data, it is evident that before the Industrial Revolution wages in Britain were relatively higher than rest of the major European countries. Adding to the higher wage levels, Britain also had lower energy prices compared to the same given European countries. To give an example, real wages of Amsterdam, Paris and London[1] have been compared with each other from near beginning of the 16th century to beginning of the 19th century (Graph 1.0). As seen from the graph, real wages in London were higher than Paris on the whole and the difference became more significant during the 18th century. Real wages in Amsterdam were comparably similar to that of London and at some points between the 17th and 18th century as indicated by the graph it even goes above London. However, as seen in Graph 1.1, energy prices of London or coal prices (cheapest available energy in the

[1] Noting that other cities in Britain including Newcastle, had even higher wages than London but our analysis will focus on major cities most specifically London throughout this paper.

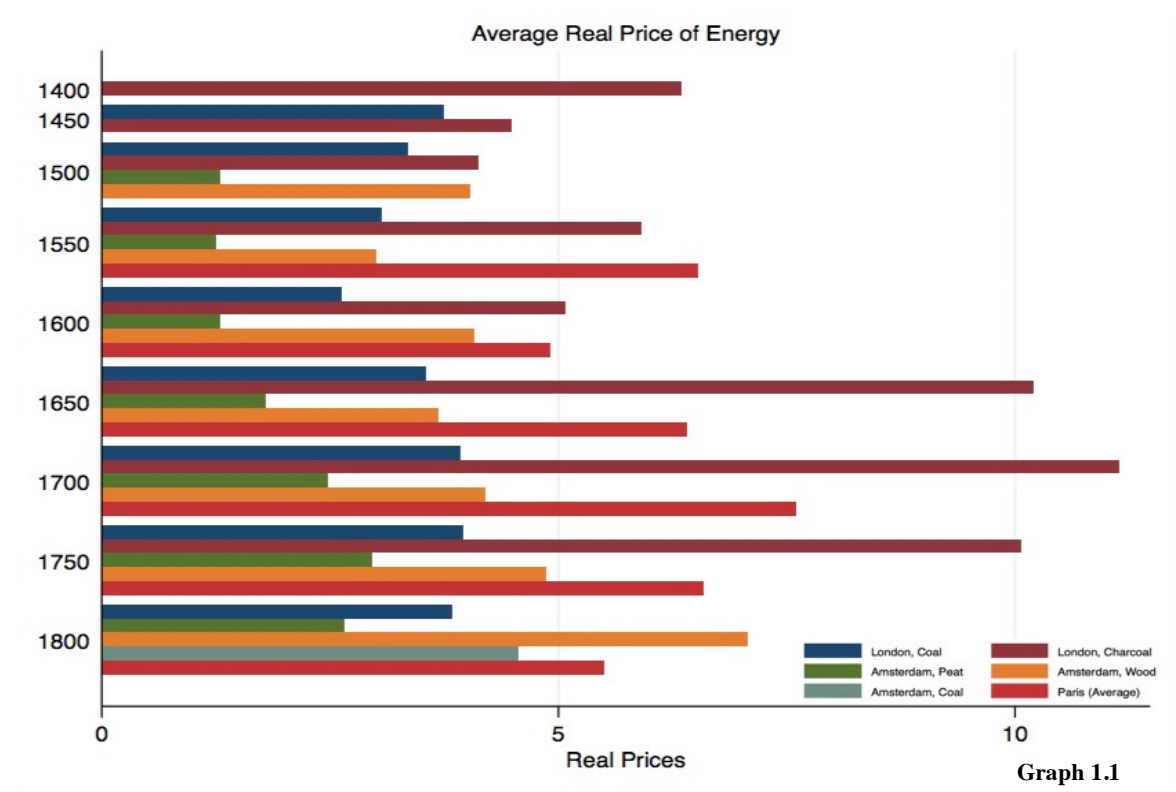
country and based on million BTUs) were lower than price of wood in Amsterdam.

When cities in the Dutch Republic and also Britain (most notably London) were starting to grow and advance, it also meant a surge in demand for fuel. The one unique difference between the Dutch Republic and Britain however was that Dutch wood prices did not rise as much as they did in London. "The reason is that peat was the backstop technology of the Dutch"[2]. As a result of the abundant availability of peat in the Dutch Republic, there was less of an incentive to transition to coal as the main source of fuel as was the case in London until the nineteenth century.



Graph 1.0

[2] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 103. Print.
*Peat was an organic fuel and unlike coal was not suffused with sulphur.



Graph 1.1

In relation to France, a critical question that can be raised is how was it possible that the British firms were able to pay more to their workers than the French did but still were able to remain competitive on a global scale. Allen answers this question by examining the technology that British firms were able to employ into their production by mentioning that "British firms developed labour-saving machinery even before the Industrial Revolution"[3]. Allen also states that cheaper energy in Britain was able to compensate for higher wages that the firms were paying to their workers and calls this compensation relationship the '*factor price frontier*'.

1.1 Major Inventions of Britain

With lower energy costs and higher wages, Britain as will be discussed in this section had an economic environment in which inventors had a reason to invent and to ultimately

[3] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 105. Print.

profit from. Therefore, it is essential to also talk about the macro and microinventions of Britain and the impact that it had on the whole economy during and after the Industrial Revolution in relation with other major countries during that time.

"*Microinventions* [are] as the small, incremental steps that improve, adapt, and streamline existing techniques already in use, reducing costs, improving form and function, increasing durability, and reducing energy and raw material requirements. *Macroinventions*, on the other hand, are those inventions in which a radical new idea, without clear precedent, emerges more or less ab nihilo[4]"[5]. The distinction between the two terms is needed and also is important because you can have a country with an abundant supply of inventors who are able to come up with new technologies or machineries but for many different reasons do not have the capacity to improve upon that technology through microinventions, unlike Britain. An example of a macroinvention is the atmospheric engine, a low-pressure engine designed by a British inventor named Thomas Newcomen in 1712 where it also was used as a test to drain a coal mine in the same year (Image 1.0 shows Thomas Newcomen's invention). This was part of an early phase of the steam engine where over the decades that passed from Newcomen's invention, through research and

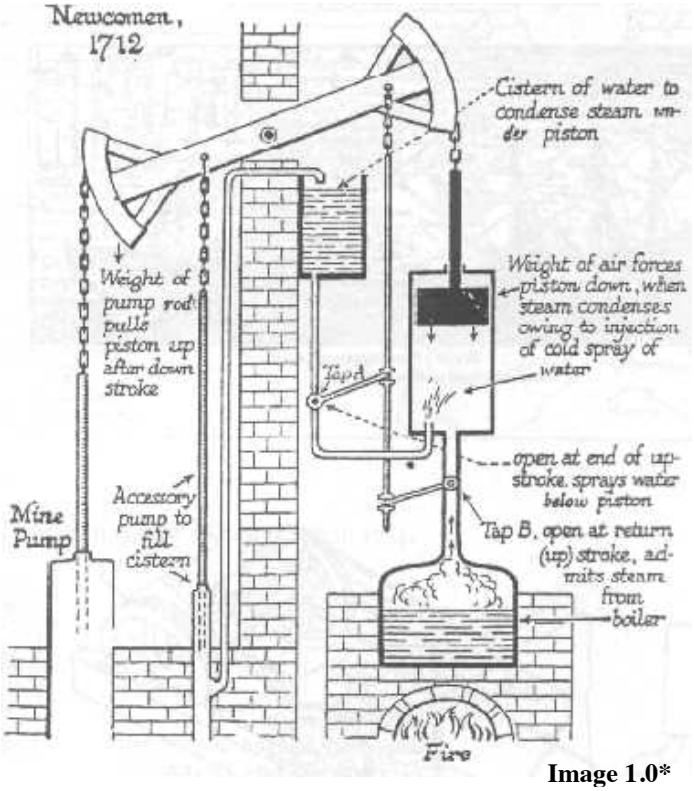


Image 1.0*

[4] Latin word meaning 'from nothing'.

[5] Mokyr, Joel. *The Lever of Riches: Technological Creativity and Economic Progress*. New York: Oxford UP, 1990. 13. Print.

development and adaptations by other inventors, steam engine became highly fuel-efficient. Since it was also able to generate power regularly, it diffused globally and was used in vast number of different industries including transportation.

The usage and demand for this technology however was only on the basis of the size of a given country's mining industry. For example, Britain at the beginning of the 18th century had a massive lead over all the other major European countries by producing "80 per cent of the tonnage in Europe and 59 per cent of the value"[6]. Germany to give an example, even though during the latter part of the Middle Ages was the mining centre in Europe, "produced only 4 per cent of the tonnage and 9 per cent of the value [during the same given time period]"[7]. The difference and the reason for sudden transformation and domination of Britain was due to coal and the fact that Britain had majority of the coal mines. "Servicing the drainage of England's coal industry is one reason why steam engine research was carried out in England"[8]. As Allen also points out, if the British had no coal industry then there would not have been any reason to invest in the steam engine or find ways to drain out the water from the coal mines.

Another reason for why coal was significant for Britain was that alternative methods were found to be possible in order to power pumps, which in example included using steam power instead of using horse gigs. Nevertheless, this technology had to be based on a country's economy in terms of how cost-effective it would be to implement it and how cheap fuel is in order to use it regularly. "At the expiry of the Savery-Newcomen patent in 1733, there were about 100 atmospheric engines in operation in England. By 1800, the total

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[6] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 161. Print.

[7] Ibid., 162.

*Image 1.0 taken from: "The Newcomen Steam Engine." *Professor Mark Csele: Newcomen Steam Engine*

[8] Ibid.

had grown to 2,500 in Britain, of which 60-70 per cent were Newcomen engines… France followed with about 70 engines of which 45 were probably Newcomen"[9].

James Watt, another British engineer, was able to improve upon Newcomen's work and developed the Watt steam engine, which proved to be vital in changing the nature of the transportation system as touched upon before and will be discussed further below in this section. What Watt did was to reduce the amount of fuel consumption in relation to what Newcomen came up with by using a separate condenser. "Watt realized that the loss of energy from chilling the cylinder could be avoided by leading the steam into a second chamber where it could be cooled"[10].

Britain saw a surge in growth in other industries as well including the textile industry. British inventor Lewis Paul was the original inventor of cotton spinning (shown in Image 2.0). The main technical problem with textiles was in the spinning where people had to use their thumbs and index fingers. Due to the highly demanding and problematic task of only relying on your hands, Lewis Paul came up with the invention where one was able to use rollers to replace the use of fingers and thereby increase both efficiency and safety.

After Lewis Paul, another British inventor, Richard Arkwright (who the credit mostly goes to when it comes to mechanization of spinning), was able to come up with a similar machine but differ with the version that Paul came up with by having two pairs of rollers instead of one while also having them move at different speeds with each other as (shown in Image 2.1). "The result was that Arkwright's machine worked whereas Paul's did not. The water frame was incapable of spinning the finer yarns, as these would have snapped when

[9] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 163. Print.
[10] Ibid., 166.

they were wound on the bobbins"[11].

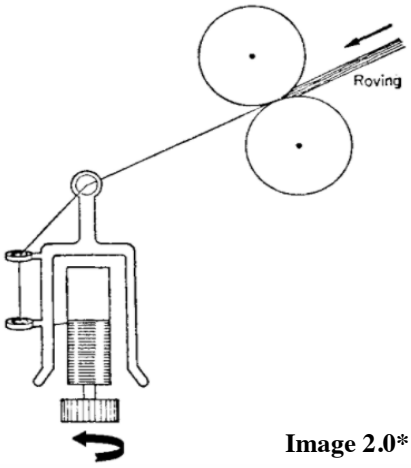

Image 2.0*

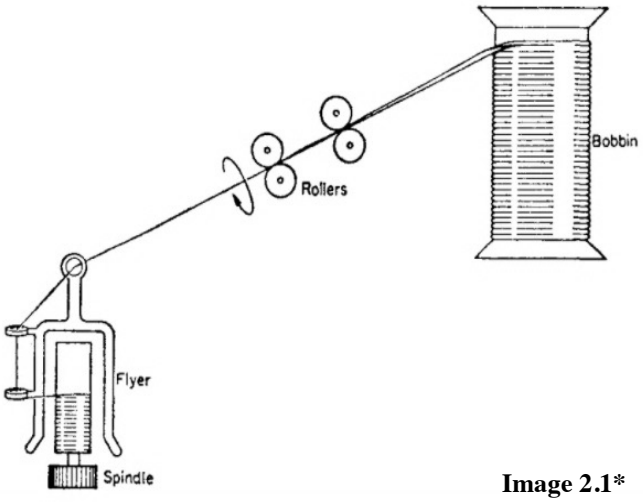

Image 2.1*

After several years of improvement and modification of the machine by different inventors, Richard Roberts, another British engineer, invented and patented the self-acting spinning mule (shown in Image 2.2). The enormous benefit of this new machine was that the movements of the carriage, which was previously done manually was now done automatically by the machine itself.

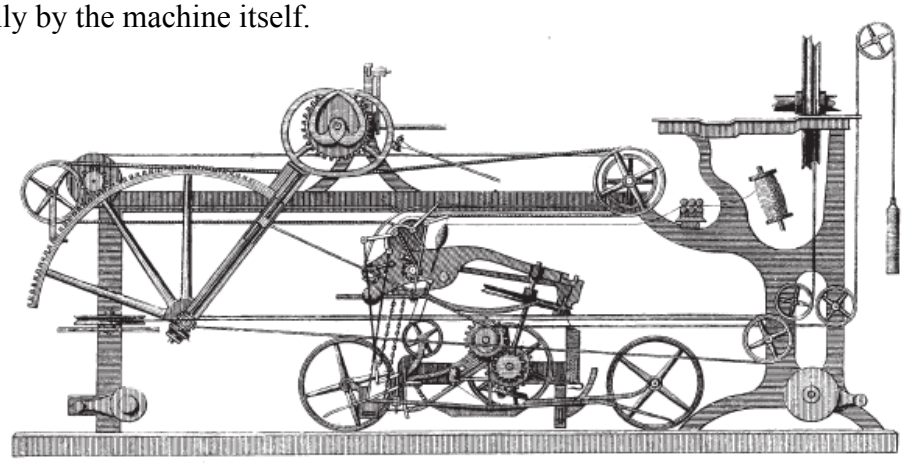

Image 2.2*

As Mokyr concludes, "The 'old' technology was the Indian hand spinner, who took

[11] Mokyr, Joel. *The Lever of Riches: Technological Creativity and Economic Progress*. New York: Oxford U Press, 1992. 96. Print.

* Image 2.0 and 2.0 are taken from D.S.L. Cardwell, *Turning Points in Western Technology*, Science History Publications.

* Image 2.2 is taken from http://en.academic.ru/dic.nsf/enwiki/1306510

about 50,000 hours. Akrwright's rollers and the mule brought that number down to around 300 hours in the 1790's and the self-actor reduced the figure to 135"[12].

One of the most important factors to note is that Richard Roberts was using the steam engine of James Watt for spinning and weaving of the machine. Unlike many other countries around the world during that time, Britain was in a unique economic position where they were able to bring to life ideas such as the steam engine and at the same use that invention to produce other technologies due to the low cost of energy and high wages.

As different industries began to develop, grow and improve their productions both in terms of having lower prices through lower costs and higher quality, including for example the textile industry, the demand for the products also began to grow as well. In terms of efficiency, it meant that demand also increased for a new form of transportation in Britain where it would be possible to travel between different distances faster and also to able to carry more goods while doing so.

Near the end of the 1770's, Watt's steam engine was used as the engine to power machinery forward. There were certainly issues and challenges originally with the integration of the steam engine with powering machinery both in terms of engineering and business perspectives. For example, "to avoid infringing [James] Pickard's patent, the 'sun and planet' gears were used [by Watt] to rotate the drive shaft with the reciprocating beam"[13]. The reason for this was that Pickard had previously patented the use of a crank, which would have connected the steam engine to a factory power shaft. At the end, through all the needed new implementations and unique solutions that Watt came up with, he was

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[12] Mokyr, Joel. *The Lever of Riches: Technological Creativity and Economic Progress*. New York: Oxford U Press, 1992. 99. Print.

[13] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 171. Print.

able to develop the rotary steam engine, which did a decent job in being able to power machinery.

As a result of improvements in the steam engine and its use in further applications and machineries, costs dropped and therefore it was not as expensive to use the engine in the transportation industry not only in Britain but also around the world. As Allen pointed out in relation with the railway industry, "railway, of course, depended on the steam locomotive, and that used high-pressure steam engines from the outset. Only these were light enough and efficient enough to pull trains. Improvements in engine design such as the tubular boiler cut their fuel costs further"[14].

In terms of shipping industry, steamships became more dominant and efficient in Britain during the Industrial Revolution simply because of the low energy cost of Britain. For example, as you moved further away from Britain, it became more expensive to use steamship as opposed to sailing ship because of the higher costs associated with coal. Again, we see another advantage that Britain had over all the other major countries during that time period because of the structure of their economy and most notably because of low energy costs and higher labour costs.

Though, it has to furthermore be pointed that it is surely not the case that Britain was the only country that the world relied on for modernization of machinery and innovative ideas. As Mokyr argues, "during the Industrial Revolution, technological progress was usually the result of the joint and cumulative efforts of many individuals [and not necessarily British inventors]"[15]. Other European countries and later on the United States

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[14] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 177. Print.

[15] Mokyr, Joel. *The Lever of Riches: Technological Creativity and Economic Progress*. New York: Oxford U Press, 1992. 83. Print.

had a large part to play in helping the global industrialization move forward. Nevertheless, the unique circumstance with Britain's economy was that through high wages, low energy costs and abundant coal mines, a market was able to be formed for inventors such as Newcomen who wanted to implement their ideas such as the steam engine. Hence, Britain offered a platform where inventors knew that the work and research they were undertaking would be worth it at the end because of the potential market that was available for their invention whereas in majority of the other countries it may have been considered a risk due to potential losses in both time and profits for the inventor. For example, if there was no need for steam engines because of either no coal mines in Britain or cheap labour to not need any form of innovation in technology then a market would not have been formed either (as was the case in a country such as France). This also meant that as one piece of technology was invented or developed in Britain, another was right behind it through a chain of innovative ideas where each one had the potential to be realized.

As a result, Britain had an interesting advantage when it came to analyzing every variable from wages to energy costs to resources that it possessed, which allowed it to be the first country to industrialize whereas this was not necessarily the case in countries such as Holland and France.

1.2 Age of Enlightenment and Human Capital

There is one critical issue that one must analyze when looking at the Industrial Revolution through the fundamental aspects of the British economy (in our case it is energy and labour costs), which is that of human capital. The scope of this topic will be limited in this paper but still must be addressed to a certain degree because otherwise we would be neglecting one of the important reasons why Britain had a heavy number of different

engineers and inventors during this time period.

For example, after the Black Death in the 14th century, wages not only in Britain but other European countries were also high. One question to ask is that why did the Industrial Revolution not happen then? A first response would possibly be that the energy market in terms of both the industry and costs associated with a particular energy were not as low as it was in Britain just before and during the Industrial Revolution, which is certainly a valid viewpoint according to Allen. However, an additional viewpoint potentially could be that there was a lack of cultural capacity due to many likely reasons (political, cultural, religion, etc.), in potential growth in human capital in Europe except in Britain. Mokyr believed that literacy and numeracy rates of the British were vital factors and pointed out to the importance of Industrial Enlightenment, which is "part of the Enlightenment that believed that material progress and economic growth could be achieved through increasing human knowledge of natural phenomena and making this knowledge accessible to those who could make use of it in production"[16].

Allen on the other hand still maintains the argument that energy prices and labour costs were the leading reasons for why Industrial Revolution happened in Britain while not neglecting the importance of literacy and numeracy rates necessarily. Firstly, Allen says that if we look at the data "there was not much difference between Britain and the rest of northwestern Europe in terms of literacy and numeracy"[17]. He also adds that the supply of inventors was relatively the same across northwestern Europe and the success of Britain to capitalize on its inventors to invent and innovate was due to the demand for the given

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[16] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 239. Print.
* This unsourced quote as Allen notes as well is taken from a manuscript from *The Enlightened Economy: An Economic History of Britain, 1700-1850* (2009) that Allen received from Mokyr.
[17] Ibid., 268.

technologies and the fact that Britain had an advantage in terms of lower energy prices. To give an example, British engineering and inventions such as pottery kilns and the steam engine heavily involved energies that were abundant in Britain (hence lower prices), such as coal. "The Dutch lacked all of these advantages, which mean they had no incentive to invent the Industrial Revolution"[18].

Importance of literacy rates will be tested in the empirical section of this paper while noting that we have to realize much more analysis will have to be done in terms of this variable, which is as mentioned beyond the scope of this paper. For example, how different was the educational system in Britain compared to the rest of Europe? How were the subjects that engineers studied such as mathematics different across Europe? And what was the ratio of inventors and engineers who came from wealthy families relative to those in the middle or lower classes?

Section 2
Empirical Analysis of the British Economy During the Industrial Revolution

2.0 Empirical Testing of Different Sectors

We will use four regressions to digest the UK economy in terms of Agricultural Output, Industrial Output, Services Output and Real GDP between the years 1583-1815. The given years are chosen because coal prices due to easier extraction and therefore increase in supply to the market, became gradually cheaper than other sources of energy such as charcoal and in the 17th and 18th century were the cheapest form of energy in Britain.

[18] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 268. Print.

Regressions 1.0 - 1.1 - 1.2 - 1.3:

$$\ln(\mathbf{AGR}) = \beta_0 + \beta_1 \ln(\mathbf{L}) + \beta_2 \ln(\boldsymbol{\alpha}) + \beta_3 \mathbf{R} + \beta_4 \ln(\mathbf{P}) + \varepsilon_t$$
$$\ln(\mathbf{IND}) = \beta_0 + \beta_1 \ln(\mathbf{L}) + \beta_2 \ln(\boldsymbol{\alpha}) + \beta_3 \mathbf{R} + \beta_4 \ln(\mathbf{P}) + \varepsilon_t$$
$$\ln(\mathbf{SER}) = \beta_0 + \beta_1 \ln(\mathbf{L}) + \beta_2 \ln(\boldsymbol{\alpha}) + \beta_3 \mathbf{R} + \beta_4 \ln(\mathbf{P}) + \varepsilon_t$$
$$\ln(\mathbf{GDP_R}) = \beta_0 + \beta_1 \ln(\mathbf{L}) + \beta_2 \ln(\boldsymbol{\alpha}) + \beta_3 \mathbf{R} + \beta_4 \ln(\mathbf{P}) + \varepsilon_t$$

L = Labour costs (real wage in London), α = Energy prices (coal prices in million BTUs), R = Literacy Rate, P = Population

	(1) lnAgr	(2) lnIndustry	(3) lnSer	(4) lnRealGDP
lnrealwageL	0.431***	0.214**	0.227***	0.300***
	(5.59)	(3.11)	(5.67)	(6.56)
lncoal	-0.245***	0.110*	0.163***	-0.0106
	(-4.52)	(2.28)	(5.79)	(-0.33)
lnpop	1.322***	0.804***	0.841***	0.994***
	(9.84)	(6.69)	(12.05)	(12.46)
literacy	0.00855***	0.0278***	0.0251***	0.0202***
	(3.76)	(13.66)	(21.27)	(14.99)
_cons	-2.267***	-4.922***	-1.158***	-1.474***
	(-3.79)	(-9.19)	(-3.72)	(-4.15)
N	236	236	236	236

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 1.0

According to the regression results, all major variables turn out to be statistically significant and positively correlated with the respected dependent variable except coal prices when real GDP is the dependent variable. Looking at the results, a 1% change in real wages (**lnrealwageL**) increases agricultural output by 0.431%, industrial output by 0.214% and services output by 0.227%. In terms of agricultural output as the dependent variable, the estimated coefficient result can say to be consistent with the theory of what Allen points out that as wages increased in London, owners of production would try to invest more in labour-

saving technologies, leading to more technological advances in the fields of agriculture through the diffusion of those technologies and hence generating higher output levels. "Britain's high wages and cheap energy increase the *demand* for technology by giving British businesses an exceptional incentive to invent techniques that substituted capital and energy for labour"[19]. This is a contradiction to what Mokyr pointed out, which was that "a labour-saving innovation means that after the innovation is implemented the capital-labour ratio rises. But in majority of cases, the absolute amount of both capital and labour needed to produce on unit of output decreased, even if that of labour has decreased more"[20]. Mokyr also states in regards to the notion of labour-saving technologies that "the producer, whether independent craftsman or mass manufacturer, will try to reduce costs by as much as possible, regardless of whether the saving is in labour or any other input. Labour costs are still costs" [21] . As the agricultural sector went through institutional changes and modernization along with enclosure of open fields and "replacement of peasant cultivation by capitalist farming"[22], more outputs were generated in agricultural sector on the whole. With the growth of agricultural sector, more food was now available to the general public since farmers for example now had surpluses leftover from their production. "This extra output made it possible to feed a large urban and proto-industrial population"[23], which led to higher wage levels in cities including London. With higher real wage levels in the urban sector, people were now able to buy even more products from the agricultural sector, which

[19] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 15. Print.
[20] Mokyr, Joel. *The Lever of Riches: Technological Creativity and Economic Progress*. New York: Oxford U Press, 1992. 166. Print.
[21] Ibid.
[22] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 79. Print.
[23] Ibid., 78.

is consistent with the regression result of positive correlation of wage levels with the agricultural output. This result will be examined more below when price of coal is analyzed as well.

In addition, literacy rates itself is also positively correlated with agricultural output since with higher literacy rates not only farmers were able to follow and understand more efficient approaches in farming but also new techniques were used including using nitrogen fertilizers. This result potentially gives an intuitive understanding to what degree agricultural sector expanded through increase of literacy rates. Hence, more research could be done on this topic to see the impact of literacy rates on the industrial sector through the agricultural sector. Noting that this regression possibly gives a better and simple understanding of the impact of literacy on the Industrial Revolution than the second regression (where we have the industrial output as the dependent variable) because we are looking at and putting more emphasis on the *origins* of the Industrial Revolution. We want to see the data and foundations of an economy before the Industrial Revolution occurred and the agricultural sector was the dominant sector throughout Europe in this time period. Having the agricultural output as the dependent variable as opposed to the industrial output allows for a cleaner approach in understanding the impact of literacy rates on the Industrial Revolution as well since according to Allen and Mokyr it was never the case that as people increased their literacy rates, the industrial output suddenly expanded. It was a gradual process where the growth in agricultural sector (although extent of it is argued between Mokyr and Allen and will be discussed further below) was the intermediary between the pre-industrial and industrial age. Pointing out again that this does not mean we should not look at the second regression to get an understanding of how literacy rates impacted industrial output but

instead that in our analysis, the agricultural sector should not be neglected.

Looking at the coefficient of price of coal (logarithm based) in regard to its impact on the dependent variable of agricultural output, we have that a 1% increase in coal prices will have a negative correlation with agricultural output while as discussed before a 1% increase in real wages in London, will have a positive correlation. Although Mokyr points out that "economic growth need not be a result of industrial change at all; it could be (and often was) rooted initially in agricultural or commercial developments"[24], this regression is more consistent with the analysis that of Allen even though Allen himself as described before believes that cities were a major reason for growth in agricultural sector. Allen makes a point that although labour costs (high wages) was significant in terms of investment in labour-saving technologies, "it was not the only way in which Britain stood apart from other countries. Even more striking was the price of energy. The early development of the coal industry in Britain mean that it had the cheapest energy in the world"[25]. Therefore, aggregating these components together we can see that labour costs and energy prices did have a significant impact on the agricultural output based on the regression results although with contrasting viewpoints between Allen and Mokyr. As Allen also states, "British economy leaped forward after 1500, cities grew, London wages were high, agriculture improved, and manufacturing spread across the countryside"[26].

When looking at the second regression, that is having the industrial output as the dependent variable, we see that there is a positive correlation between coal prices and

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[24] Mokyr, Joel. *The Lever of Riches: Technological Creativity and Economic Progress*. New York: Oxford U Press, 1992. 82. Print.

[25] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 81. Print.

[26] Ibid., 106.

industrial output (although not strongly significant based on the result), which means that increases in price of coal would increase industrial output. There are complications with this result because the firsthand intuition would be that the relationship between the two should be negative. That is, as energy prices drop then the industrial sector should grow. While this thinking remains valid in terms of economic intuition, there are several other aspects that have to be realized as well (similar to what we discussed for literacy rates). For example, Mokyr believed that agricultural revolution was a major reason for the expansion of the urban and industrial sector and economic growth. If we go back to the first regression, we see that as discussed before there is a positive relationship between wages and then a negative relationship between energy prices and agricultural output. By Mokyr's intuition, the growth in agricultural output would then lead to growth of industrial output, which means that we would not have to look at the direct relationship between energy prices and industrial output but rather base our decision of why the industrial sector expanded indirectly through agricultural output. Allen on the other hand has a different viewpoint, although not completely opposing Mokyr's analysis by stating the following:

> "There is some truth in the standard narrative [of agricultural revolution causing the industrial expansion], but causation ran more strongly in the opposite direction. London and the proto-industrial sectors were the engines of growth. Their expansion raised wage rates and few labour out of agriculture … the agricultural revolution was the result of the growth of cities and manufacturing".[27]

Hence, based on Allen's analysis we can see his argument that we should not simply assume that growth in the agricultural output (or negative energy prices and high wages) led to growth in the industrial sector and vice-versa but rather it was the combination of each other at the early stages of growth and then agricultural sector and outputs expanded because

[27] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 79. Print.

of the expansion of the urban and industrial sector. As he also points out, "not only did bigger cities lead to more efficient farms, but better farming [also] led to bigger cities"[28]. Therefore, through Allen's reasoning we again see that there is an indirect relationship between energy prices and industrial output because in this case the reasoning is that combination of agricultural and industrial growth *reinforced* each other.

We can test these two reasoning by Allen and Mokyr by doing the following regression where have the industry output as the dependent variable and agricultural output as the independent variable while using IV estimators for **AGR**, to avoid the problem of simultaneity. Therefore, the IV estimators used are Agricultural Production Index (AgrPro), Capital Index (CapInx), Labour Index (LabInx) and Seed Index (SedInx) collected from data by Allen, where each one is only based on the agricultural sector and not correlated with the error term when industrial output is the dependent variable.

Regressions 1.4 - 1.5:

$$\ln(\mathbf{IND}) = \beta_0 + \beta_1 \ln(\mathbf{AGR}) + \varepsilon_t$$
$$\ln(\mathbf{AGR}) = \Phi_0 + \Phi_1 \mathbf{AgrPro} + \Phi_2 \mathbf{CapInx} + \Phi_3 \mathbf{LabInx} + \Phi_4 \mathbf{SedInx} + \nu_t$$

The result of the regression using IV estimators is now as follows:

	(1) lnIndustry
lnAgr	1.730*** (28.04)
_cons	-7.564*** (-25.92)
N	236

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

There is a statistically significant and positive relationship between lnAgr and lnIndustry with the p-value being less than 0.001. Thus, we can say that Allen and Mokyr's analysis although with minor deviations from each other, is consistent with the regression result and that agricultural

[28] Allen, Robert C. *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge UP, 2009. 117. Print.

revolution did in one form or another have an impact on industrial output and expansion. As a result, even though there is a positive relationship between energy prices and industrial output, we have to look at other factors as well to make a decision on the relationship between these variables.

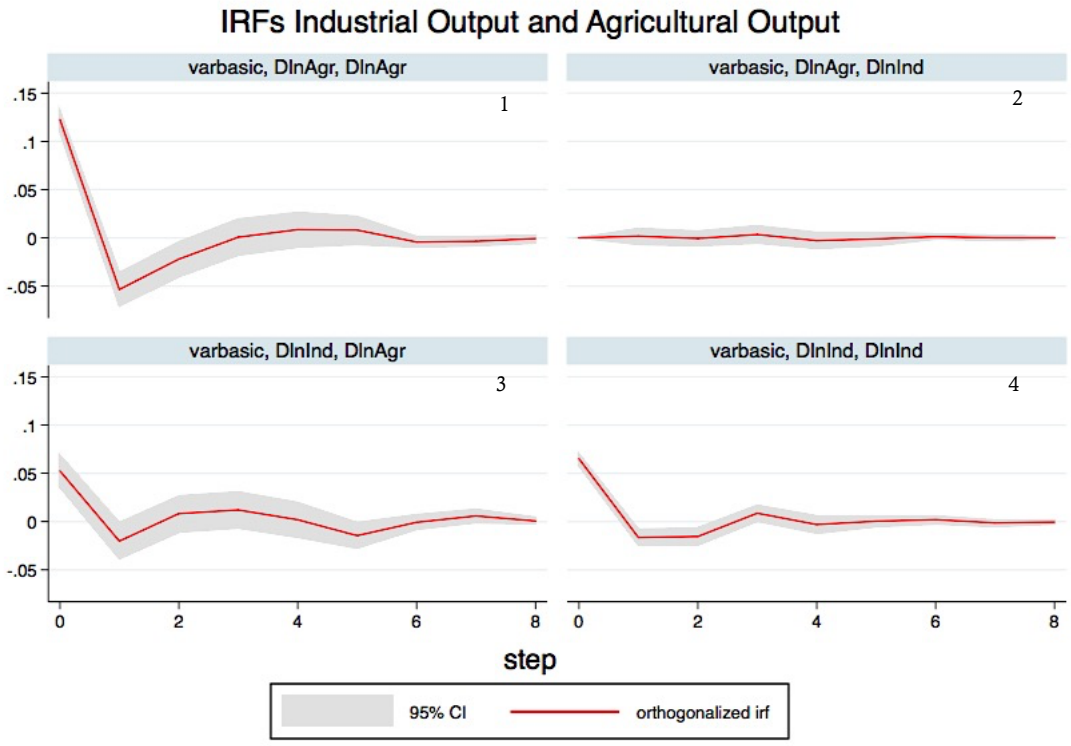
Another possible reasoning for the positive relationship between energy prices and industrial output includes international trade of coal as a commodity in Britain. For example, if one of your main sources of exports is coal, then rising coal prices to a certain degree would have a positive impact on your net exports and hence economic growth and therefore expansion of different sectors in that economy. Consequently, it is difficult to make explicit assumptions and reasoning on the outcome of coal prices on industrial output through expansion of agricultural output by only looking at the second regression where industrial output is the endogenous variable.

Another way to look at the impact of either sector on each other is to construct a VAR model and see the impact of an Industrial Output shock on the Agricultural Output or vice-versa and evaluate the result (to see the detailed explanation of the method of how VAR was constructed, see Appendix A). Based on the Granger causality Wald test, we get that the first-difference of log of Agricultural output (**DlnAgr**) does not Granger-cause the first-difference of log of Industrial output (**DlnInd**). However, when we look at the reverse, we see that with p-value being less than 5% **DlnInd** will in fact Granger-cause **DlnAgr**, which again is consistent with the analysis of Allen as previously pointed out.

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
DlnInd	DlnAgr	1.3351	4	0.855
DlnInd	ALL	1.3351	4	0.855
DlnAgr	DlnInd	11.817	4	0.019
DlnAgr	ALL	11.817	4	0.019

Looking at the IRFs below, the first variable is the impulse variable and the second variable is the response variable. If we look at the IRF number 3, we see that if we had a 1 standard deviation impulse to **DlnInd**, we would have a 0.05% increase in **DlnAgr** at the beginning then dropping below zero before converging back to zero again over time.



What we see is that the result this time is mainly consistent with that of Allen since he pointed out that causation ran more strongly in the direction of the industrial sector expanding the agricultural sector and not vice-versa.

It is clear that there are consistencies with both Mokyr and Allen's analysis from the regression results (regressions 1.0 and 1.1) both when having the agricultural output and

then industrial output as the dependent variables. However, when it came to the results from the VAR model, the analysis was more consistent with that of Allen because of the fact that Mokyr believed that growth in the agricultural sector would lead to growth in the industrial sector, whereas the result did not necessarily show this. At the same time, we need to take into account that we have to look at the results with more than one perspective since there are indirect relationships between different variables including the second regression (regression 1.1) when energy price is the exogenous variable and industrial output is the endogenous variable. Through this way of analyzing the Industrial Revolution (or in our case industrial output), we will be able to look at other factors that had a part to play in making Britain be the first country to industrialize. For example, Mokyr not only looks at quantitative results but also places significant emphasis on institutional, religious, political and socioeconomic factors that evolved over time and hence changed as a result in Britain. These changes as Mokyr believed, led to more investments in new technologies to bring about technological innovations and then growth in different economic sectors (including industrial) rather than directly linking the cause of Industrial Revolution or growth of industrial output in our case to energy prices and labour costs.

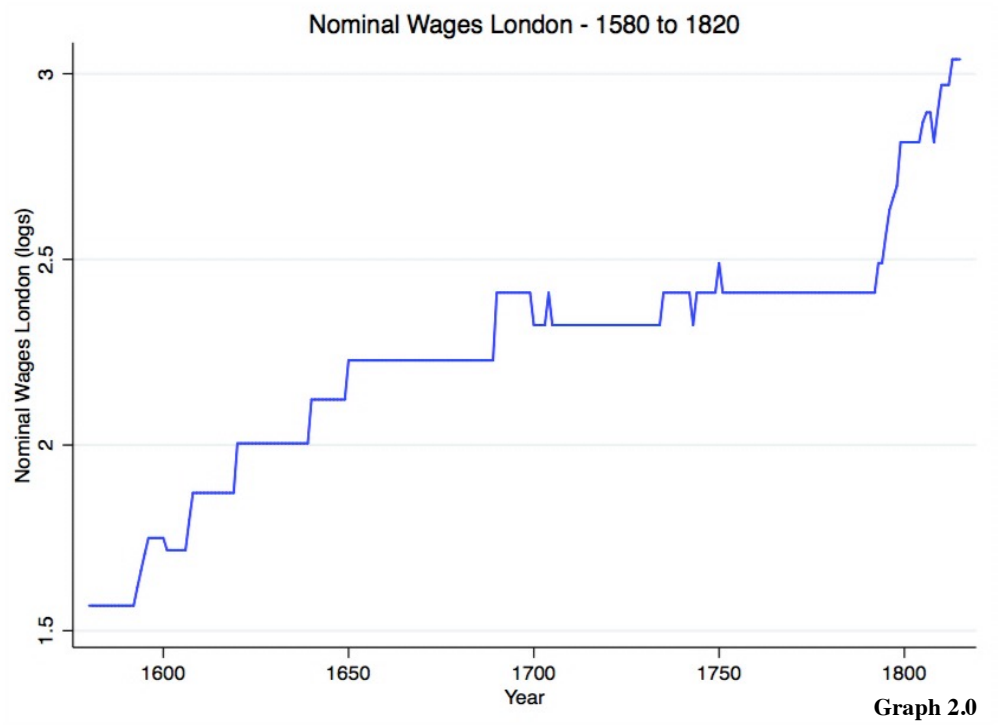
2.1 Relationship between Nominal Wages, Coal Prices and Industrial Output

A second approach we can use to test the relationship between wages, coal prices and its impact on the Industrial Revolution is to see how these variables correlate with industrial output over a long period of time. Therefore, using a combined data from Allen, Broadberry, Campbell, Klein, Overton and Leeuwen, we will do a cointegration test and see if the difference between these variables remains stationary through the given time period (the detailed method of cointegration is given in Appendix B).

Noting first that nominal wages of London (Graph 2.0) are being used instead of real

wages for two reasons. One reason is nominal wage because this is the actual wage people would receive (ex. salary is nominal) and therefore incorporates the trend in prices as well whereas real wages gives you the actual number of goods you can buy with that wage. In addition, real wages in London were relatively stationary up until around 1620's to mid 1700's whereas nominal wages trended upwards on a longer time period.

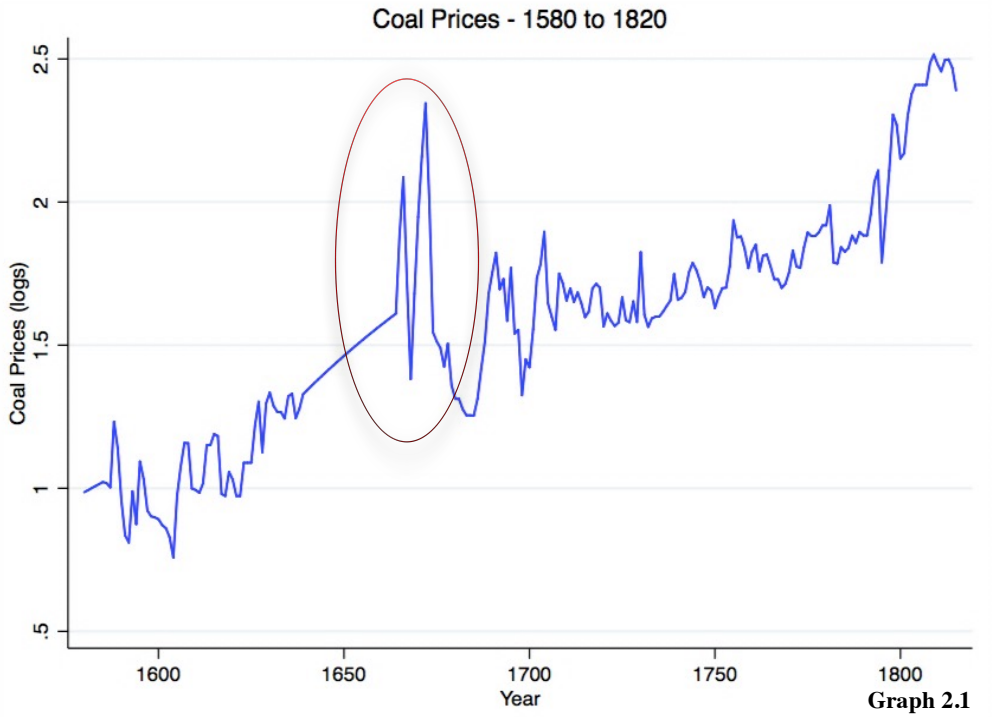
In terms of coal prices (Graph 2.1), as shown with the circular red figure on the graph there was a shock effect between the years 1645 to 1675, which resulted in sudden upward and then downward impact on prices as a result. This shock effect also played part in the cointegration as clear from the graph, which will be discussed later.



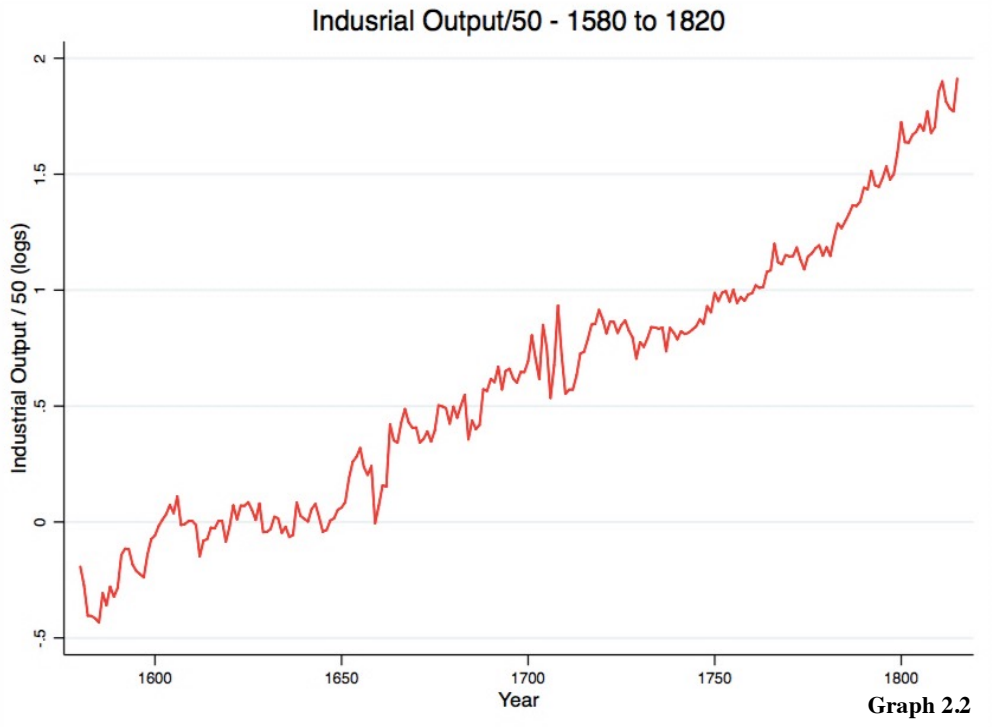
Graph 2.0

Industrial output (Graph 2.2) also shows an upward trend from the year 1582 to 1815 with minor deviations during this given time period. This trend is divided by fifty to give a smaller difference between coal prices, nominal wages and industrial output on the whole and it will not make an alteration in the analysis of the relationship between these variables

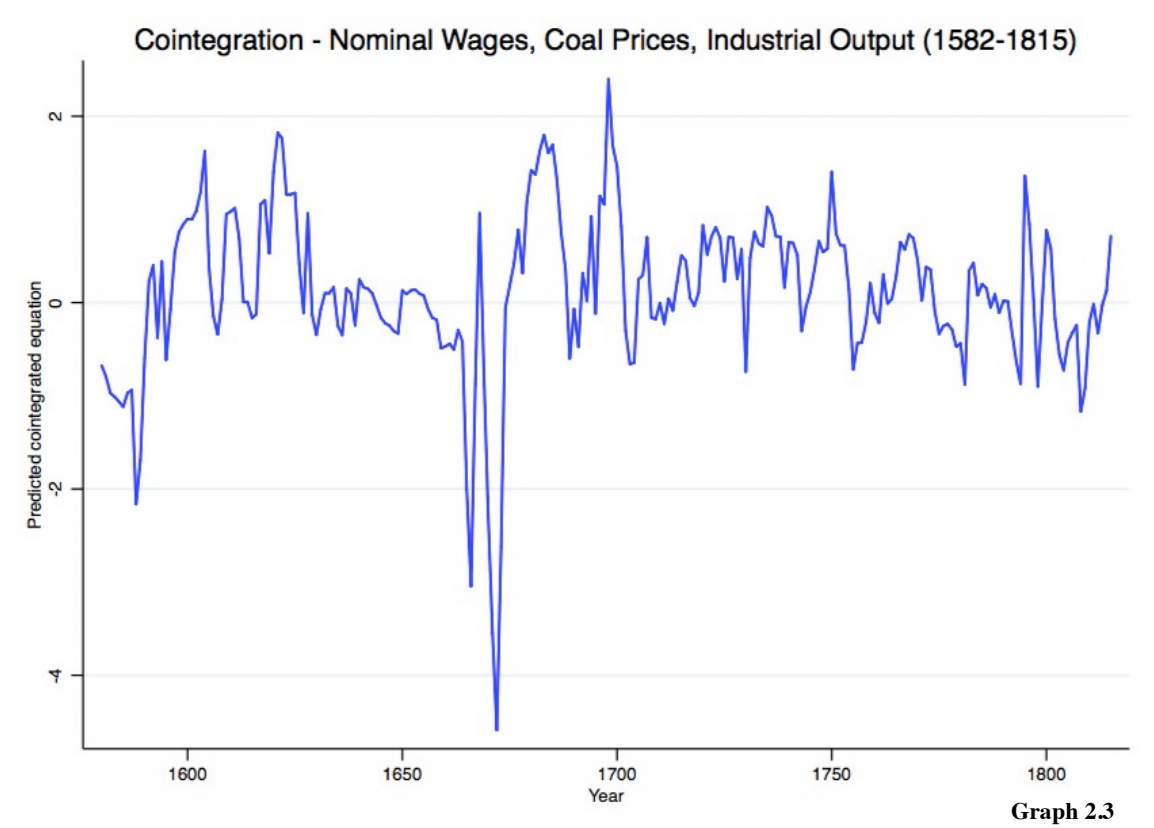
since we are looking at the relationship of trends. In terms of the cointegration figure (Graph 2.3), we see that the figure is stationary. This result is similar to Allen's analysis when he looks at the relationship between prices of energy, labour costs, proto-industry, urbanization and agricultural productivity in Britain.



Graph 2.1



Graph 2.2



Graph 2.3

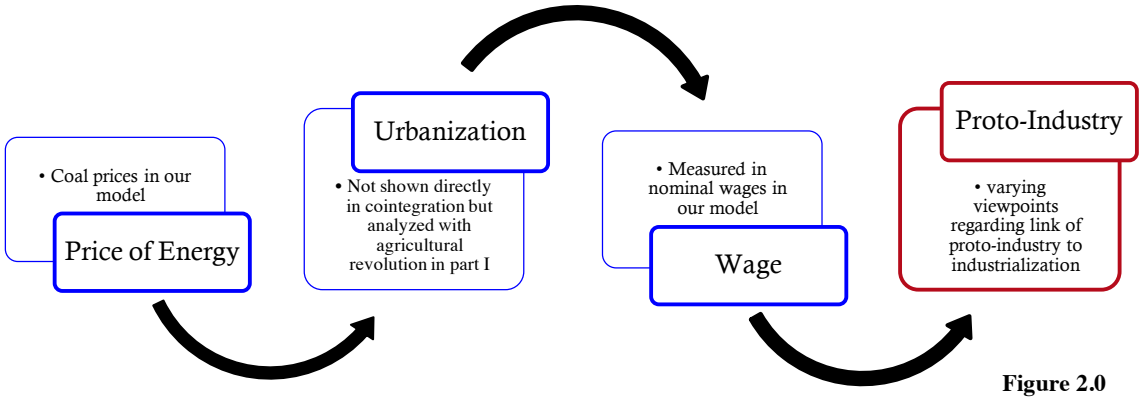


Figure 2.0

Figure 2.0, taken from *The British Industrial Revolution in Global Perspective*, adjusted to include only components that are the focus of this paper (excludes for example international trade boom and its linkage with urbanization). The difference not in terms of the end analysis and results but the setup of the model from Allen and the cointegration figure done before is the last element, which is *Proto-Industry*. The reason for this difference is that economic historians have had varying viewpoints regarding the impact of proto-

industry on industrial output and expansion of the industrial sector. For example, Mendels (1972) believed that the first phase to industrialization was proto-industry. Therefore, if we take that belief into consideration then the cointegration result will be consistent with Allen's model. Still, there is also another difference between the cointegration result and the model by Allen. The difference is that cointegration result by this paper is based on relationships through time with each one based on the same time period (or time periods within a small marginal difference from each other) whereas Allen's model states that one variable (for example price of energy) causes the other (urbanization) in definite terms. Therefore, in order to compare and contrast the two results we have also have to account in these differences between the two models since it does play a critical role in understanding the interaction of wage levels, labour costs and industrial output in Britain historically.

Conclusion

The British economy had comparative advantage in having low energy prices but also at the same time having high labour costs. The regression results and analysis of this paper although with some deviations, show signs of consistency with the analysis and works of Allen and Mokyr. When having the agricultural output as the dependent variable, there is a match between the works of Allen and Mokyr and the results since there is a negative relationship between energy prices and agricultural output and a positive relationship between wages and agricultural output. When the industrial output is the dependent variable, the analysis gets more complicated but again show signs of consistency with Allen and Mokyr because we see that there is an indirect relationship on industrial output through growth of agricultural output. Therefore, even though the regression result shows a positive

relationship between energy prices and industrial output, it does not necessarily mean that the results are different than that of Mokyr or Allen but instead we have to think about it through different perspectives and see that there can in fact be an indirect relationship through agricultural output while also considering the impact of international trade that higher energy prices would have on the industrial expansion and economic growth.

Allen places a greater role in researching about the impact of energy prices and labour costs while Mokyr spends a vast portion of his book looking at the Industrial Revolution through a qualitative framework. For example, Mokyr also talks about the origins of Industrial Revolution by researching and talking about the change in human thinking, institutions, politics and religious authority on rules and regulations, which would then ultimately lead to more freedom in human curiosity and hence rise of innovations and economic growth in Britain. The scope of this paper is limited to energy prices and labour costs on industrial output but one can also test other viewpoints of Mokyr by testing for other variables. For example, one might start testing to see the percentage change in religious people between the time period of 16th century to 19th century and see if people's thinking and ideologies started to change before the Industrial Revolution which in turn had an impact in forming the Industrial Revolution.

Through the cointegration test done in part two of this paper, the result was again consistent with that of Allen in terms of a relationship that exists between energy prices, labour costs and expansion of the urban sector and industrial output (if assuming proto-industry had a role to play in industrial expansion). However, noting again that the cointegration model is based on variables that move with each other through the same time period or with small marginal differences from each other whereas Allen's model is based

on one variable causing the other.

On the whole, what we see from the results of the two parts of this paper is that energy prices, labour costs and industrial output do have a relationship with each other and play a part in causing the Industrial Revolution (most notably originally in Britain) even if there are contrasting viewpoints regarding the degree of the impact of these variables.

Appendix A:

VAR (basic):

- A prerequisite with vector autoregression is to use stationary variables.
- Since log of industrial output and log of agricultural output from 1580 to 1820 is not stationary, we take the first difference named **DlnInd** and **DlnAgr**, respectively.
- We can also check for stationarity through the following method:
- Based on Dickey-Fuller Test we want to see if the variables are stationary or not stationary (or integrated of order 1) but if we transform the variables through first differencing then it would make it stationary
- Null hypothesis of the test is that there is unit root and that means that the series is non-stationary and alternative hypothesis is the opposite
- Before attempting the Dickey Fuller Test, we check for the optimal lag selection, which is shown using the 'varsoc' command
- Results would then indicate stationary with first differencing (our first-differenced variables as indicated before are DlnInd and DlnAgr).

Granger Causality Wald Test:

- The null hypothesis if true states that the variables are jointly not significant whereas the alternative hypothesis states that they are significant.
- In our model, with DlnAgr (first-difference of log of agricultural output) does not Granger-cause DlnInd (first-difference of log of industrial output) because p-value is higher than any significant alpha (ex. 1%, 5%, 10%).
- On the other hand, DlnInd does Granger-cause DlnAgr since p-value is less than 5% and/or 10%.

Appendix B:

See Appendix A for how to checking for stationarity of variables.:

Johansen Test:

- Given the check for non-stationarity of the variables, the Johansen Test now tests for validity of cointegration between those variables
- If the test-statistics is larger than the 5% critical value then we reject the null hypothesis of no integration in favour of alternative hypothesis of validity in cointegration in our model
- Results indicate cointegration exists between the three variables

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