“Energy efficiency and the productivity race in Industry (1870-1935)”

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Abstract

This is a very preliminary paper and we would very much appreciate your feedback. We are currently working on the extension of our database and we are hoping to be able to present more complete results during the conference.

The major aim of this paper is to analyze energy use and particularly energy productivity in some of the major manufacturing processes, such as iron and steel or paper production. Energy, as one of factors of production and substitute to labor, has often been neglected in various productivity benchmark studies. It is the aim of this paper to further investigate this relationship between energy and labor productivity, with a specific focus on the manufacturing industries across Europe and the US.

1. Introduction and motivation

Growing material and energy consumption associated with low-income countries adopting western patterns of consumption are commonly discussed as potential threats to meeting global emission targets. This has, at the same time, stimulated research into past energy intensity trends with specific attention directed towards energy intensity of the manufacturing sector which has historically shown the highest levels of energy consumption. Consequently, energy efficiency and improvements thereof have become a buzzword in the political arena as increasing energy efficiency allows for continuous economic growth while at the same maintaining or even reducing the absolute levels of energy consumption and global CO\textsubscript{2} emissions (Birol and Keppler, 2000).

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The move away from biomass-shaped economy to a mineral economy, as we have witnessed over the past 200 years in the developed world, fundamentally transformed the established economic structures, created new materials and needs and raised productivity levels to unprecedented heights. Much research has been devoted to the role of various factors of production in the productivity growth since the first industrial revolution, some more in depth than others. The rise of the US manufacturing is often put forward as an exceptional tale of unique labor productivity growth, rapid technological change and an apt organization style (Broadberry, 1998). The American exceptionalism and consequently the national differences in labor productivity in various manufacturing sectors have been a focal point of many comparative productivity studies, particularly among the Western countries. According to some (Allen, 2014, 2009; Broadberry and Irwin, 2006; Habakkuk, 1967), labor scarcity in some parts of the world stimulated not only technical progress and shifts in the composition of investment; it also had a tremendous impact on productivity changes within various industrial sectors. Indeed, historical rates of labor productivity have been rising virtually in all countries. It has been estimated that since the mid-18th century global industrial labor productivity increased by a factor of 200 (Grubler, 1998). At the same time, global output grew 100-fold (ibid). Although most studies identified this common trend, little attention has been devoted to the role of energy utilization in productivity growth or as a substitute to labor. In fact, the use of fuel and power are some of the “most homogenous natural resources and the two most comparable to labor” (Habakkuk, 1962). This is particularly surprising, given the fact that labor productivity differences at a sectoral level are normally attributed to the differential use of energy and capital.

It is the aim of this paper to further investigate this relationship between energy and labor productivity, with a specific focus on manufacturing industries. The time scope of this study stretches over a period of 60 years which was characterized by increased deployment of steam, combustion engines and electric motors and other labor-saving machinery in European manufacturing, though little is known about the actual energy intensity trends of various processes. Also little is known about the cross-country differences in energy productivity and the drivers of steam utilization. Contrary to most other studies, this paper’s geographical scope will not be confined to Britain and the US. Instead, we
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present unique comparisons on the evolution of energy as well as labor productivity for a group of six European Countries (Denmark, Germany\(^2\), Portugal, Sweden, the Czech Lands and the UK) and the United States, each with a varying degree of industrialization, domestic coal resources and trade dependence. Contrary to other studies, this allows us to study the importance of various production factors in countries which industrialized early on as well as some late-comers.

The main research questions of this paper are:

- What is the development of energy productivity in various sectors of manufacturing?
- Are there substantial differences between the most developed countries (the ‘core’) and industrializing countries (the ‘catch-up’ group) over the period 1870-1935?
- How does the development in energy productivity relate to that of the labor productivity?

2. The labour productivity differences/technology debate

The major theoretical framework which relates to this paper is the extensively researched field on differential levels of labor productivity (Allen, 2012; Broadberry, 1998; Broadberry and Fremdling, 1990; Broadberry and Irwin, 2006; Veenstra, 2014). Differences in labor productivity, usually focusing on the United States, the UK or Germany, are often attributed to the differential use of energy and capital (Habakkuk, 1967), but rarely related to each other. The increased use of steam technology and mechanization (and thus capital deepening of various productive sectors) is generally considered to be the major driver of increased labor productivity, together with improvements in human capital, organization of production and scale increases. Britain at the beginning of the first industrialization had the largest incentive to introduce modern labor-saving technology as a response to relatively high labor costs (Allen, 2009). It has been shown that during the 18\(^{th}\) century the country was unique in having ‘particularly high wages and low energy prices’ (Allen, 2009). This fit well with the newly introduced technologies which enabled certain degree of labor-savings while consuming relatively cheap and abundant energy, a setting which was profitable in a country like Britain but unlikely to be reproduced in other countries with different relative factor prices (Allen, 2009; Kander et al., 2013).

\(^2\) Germany will be included in future versions of this study.
The industrial revolution would only spread to Europe when improvements in the efficiency of the steam engines occurred, by reducing energy costs and increasing the incentive for low wage countries to mechanize (Allen, 2009; Kander et al, 2013). In less developed countries, such as India or Egypt, without domestic coal reserves and highly dependent on firewood energy, this development pattern could not be reproduced. With an abundance of cheap labor, the relative costs of labor to energy did not lead to the adoption of modern technology (Allen, 2014).

More than coal, energy and natural resources endowments are credited as major factors in 19th century industrialization of the United States and subsequent higher technology and labour productivity in relation to Britain. Paul David (David, 1975) developed a model that explained the persistence of advantages regarding technology and their impact in economic performance. He considered capital and natural resources as non-separable and argued that the opportunities for future technological accumulation in the nineteenth century were biased in favour of the choice which was more capital intensive. Due to her vast natural resources, America had incentive to mechanize and chose the most capital resource intensive path of development, making opportunities for economic performance greater in America. David saw then technological progress as a path dependent process where the final choice of technique depended on the initial factor endowments composition. Low wage countries could be locked in on a labour-intensive path, without much potential for technical change.

From this literature, we can see that the availability of natural resources, and coal in particular, is often seen as a prerequisite of industrial development (Wrigley, 1988; Kander et al, 2013, Grubler, 1998). Although this may be a highly valid consideration for earlier periods, this precondition becomes of secondary importance with the technological changes in modern transportation (Grubler, 1998). Thus, instead of focusing on resource availability as a cause of differential development across countries, it is important to assess those disparities with ‘technology and technology gaps’ as the major agent of change.

This transition from biomass driven production (mainly muscle power – food and feed) to a production increasingly dominated by non-renewable energy resources, had not only profound effects
on the adoption of new technology and actual productivity but also on the energy productivity of various productive sectors (Schurr and Netschert, 1960). Despite the importance of energy as a major factor of production and its substitutability properties to labor, very little research has focused on the actual energy productivity in the early stages of modern economic growth. This is likely due to the limited data availability on energy consumption in various sectors prior to the 1970s3. After 1970 energy productivity differences across countries are found to be larger than the differences in labor productivity (Mulder and de Groot, 2004). Indeed, although there has been some degree of energy productivity convergence in the world manufacturing sectors since 1970 and particularly after 1990s, the cross-country differences in the utilization of energy remain larger than those in labor productivity (Mulder and de Groot, 2004; Mulder, 2015). At the same, the historical rates in energy productivity growth can hardly match those achieved in labor productivity. For example, in the iron and steel sector, energy productivity increased by a factor of 5 over the whole 20th century (Smil, 2014). This means that the amount of energy consumed to produce one ton of steel dropped to some 20% of that consumed in 1900. This seems like an impressive magnitude of change, until compared to the increases of 1,000-fold in labor productivity (Smil, 2014). In fact, while it took 3,143 man-hour to produce one ton of steel in 1920, this has been reduced to some 0,003 man-hour nowadays (Berry and Ritt, 1999). Even though, cross-country comparisons of manufacturing labor productivity are some of the most complex tasks, given the differences in output-mix, working hours arrangements or educational attainment, generally a pattern of convergence in global manufacturing labor productivity has been identified (Barro and Sala-I-Martin, 1992; Dal Bianco, 2016). Following the established framework, convergence can be understood from two levels. First, convergence occurs when there is a diminishing trend in cross-country differences in productivity (Barro and Sala-I-Martin, 1992), thus the absolute levels of productivity begin to level out. At the same time, convergence can also be understood from the point of certain productivity catch-up, here lagging countries catching up to the productivity leader. Despite the growing trend of overall manufacturing labor productivity, differences persist at the sectoral level and often a level of aggregation have proven crucial for any quantitative

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3 The International Energy Agency database, the most used in energy productivity studies, records data on final energy use in OECD countries only from the 1960s, and to non OECD countries from 1971 onwards.
assessment of potential convergence (Mulder and de Groot, 2004). Generally, labor productivity differences at a sectoral level are normally attributed to the differential use of energy and capital.

Although long-run historical analysis of the interplay between energy use and labor productivity are rare, some attempts have been made, particularly within the scope of increased electrification. In Sweden, the increasing share of electricity in the manufacturing sector was found to be a strong driver of both labor productivity (Schon, 2000) and energy productivity (Enflo et al., 2009). Even though the relationship is rather complex due to the reciprocal impact on both labor and energy productivity, the role of increasing use of electric motors can be summarized as follows. During the First Industrial Revolution the move from water to steam power brought little change to the organization of the manufacturing plants, while at the same time replacing some of its workers. Labor productivity increased by some 60% between 1880 and 1900 (Grubler, 1998). Steam engines thus provided some significant breakthroughs in both energy use as well as labor productivity, but due to its nature – static, immobile and heavy - steam engines represented also certain limitations to usage. The introduction of electricity as the driver of mechanical power in manufacturing dates back to 1884 in the US, but the first productivity gains could first be observed during 1920s, by which time when electric motors supplied over 50% of all mechanical power in manufacturing (Devine, 1983). The reason for this relatively long lag in productivity gains is to be explained by the technological nature of electric drives. In fact, in the early stages of electrification, electric motors were simply used to replace centralized steam engines with identical power distribution system with each machine having to be connected to the centralized electric motor (Grubler, 1998). The overall efficiency of an electric motor utilized in a same manner as a steam engine, remained unchanged. In order to increase the efficiency of the newly implemented electric motors, it was necessary to fundamentally change the organization and layout of producing plants. Only in this sense, could the decentralized electric motor be now used to power each machine individually and thus materialize on its flexibility. At the same time, individual motors could be operated (turned on/off) only when needed (Devine, 1983). In turn, the organizational changes and the full deployment of electric motors had a tremendous impact on labor, energy and capital productivity growth. In the US, labor productivity in the manufacturing is believed to have
increased by a factor of 100 only in the decade 1920-1930 (Devine, 1983). Similarly, for the US, Schurr et al. (Schurr and Netschert, 1960) and later Jorgenson (Jorgenson, 1984) provide an analysis of the relationship between growing energy and labor productivity. According to the authors, the substitutability between more expensive labor and less expensive energy cannot explain fully the productivity growth. In fact, between 1920 and 1955 both the energy intensity (energy/output) and labor intensity (labour/output) declined which calls for a more thorough investigation of the role of technical change. Both Schurr and Jorgenson further argue that the role of electrification was in fact critical in the period after 1920, supported by the improvements of thermal efficiency of conversion of fuels into electricity as well as the widespread use and flexibility of electricity in the manufacturing processes (Jorgenson, 1984). This finding corresponds with other research on the substitutability of various factors of production, which generally find some substitution between labor and nonelectrical energy, on the other hand electricity is often seen as a complementary and an additional driver of productivity growth (Iqbal, 1986; Schurr, 1990). In Sweden 1900-1990, for example, electricity was found to be a largely ‘complementary to new technology and skills’, having a profound impact on the overall productivity (Schon, 2000).

It is believed that historically the energy / output ratio has undergone some significant changes due to three major drivers (Schurr and Netschert, 1960). First (1), the shifts among primary energy sources had a tremendous effect on the energy intensity of production. This was for example the move from animate power to inanimate (often fossil fuel) power. Second (2), the move away from primary energy sources to ‘processed and converted energy products’ had an impact on the energy intensity of production, with, for example, increased deployment of electricity. Third (3), and as a direct consequence of both aspects (1) and (2), increased mechanization changed the composition of energy intensity, with first a move towards steam and later a replacement of steam by electrical motors (Schurr and Netschert, 1960).
3. Methods and data

Energy intensity is a measure of energy consumed to produce a certain product or deliver certain services. In the manufacturing sector, energy intensity usually describes the energy needed to produce 1$ worth of product. In energy studies, this ratio is used to express the evolution of the efficiency of production. The major drivers of differential energy intensity across countries are technology and production methods, but also differences in the quality of final output or pricing mechanisms if monetary values are considered (Birol and Keppler, 2000). For the purposes of this study and also given the focus on basic commodities, energy intensity of production ascribes the energy needed to produce one common measure of output (in this case 1 ton of final produce) and follows the method of the ODEX indicator which was developed to capture sectorial energy efficiency following this equation (Morfeldt & Silveira 2014):

$$U_i^t = \frac{E_i^t (G_c)}{A_i^t (t)}$$

(1)

Where UC refers to unit consumption of the industrial sector in a country (i) in one year (t) is defined as the energy consumption of the sector (EC) divided by total activity (A) of the sector. Alternative expression of energy intensity is energy productivity, which is an output-based measure of relative energy consumption. In simple terms, energy productivity is basically an inverse function of the often used measure 'energy intensity'. In labour studies, generally, labour productivity is more accepted measure of efficiency. For the purposes of this study and especially when both utilization measures of energy and labour are paralleled to each, we will resort to the 'energy productivity' term.

Energy consumption is measured in GigaJoules (GJ). We include wind, water-power, coal, firewood and oil as primary energy carriers. Secondary forms of energy such as charcoal, coke and electricity are measured by their primary energy equivalents. This means that we include the energy incorporated in the fuels necessary to produce 1 kWh of electricity, the firewood necessary to produce 1 ton of charcoal and the coal necessary to produce 1 ton of coke. It is also very likely, that in the future drafts
of this paper we will need to address more in depth the issue of different energy mix across countries, as this is likely to affect the final measure of energy intensity.

Production volumes are measured in metric tonnes. The main reason as to why physical quantities (and not monetary values as commonly used in other productivity studies) are used is to enable cross-country comparability. It has been shown that using output values can be misleading, partly due to the issues associated with historical exchange rate conversions but mainly because “differences in the level of development can affect the overall price level” (Broadberry and Klein, 2011). On the other hand, using physical quantities may also be problematic due to differences in the product mix and quality (Larsen, 2001). Within this paper, for example, production of one ton of cotton goods may seem far more energy intensive in the UK (with a highly mechanized textile sector) compared to some other late-industrializing country, though the actual quality of the British cotton cloth may on average be higher with a higher density or advanced prints and other refinements. This drawback of our approach thus requires some degree of attention, particularly when discussing cross-country differences in energy intensity.

We use a mixture of well-know and less-known sources to establish our energy intensity and labour productivity benchmarks. They include not only industrial or production census that are commonly used in labor productivity studies, but also industrial statistics, sectoral reports or monograph surveys of specific regions. Table 1 show some of the main sources used by country:

Table 1. Main sources by country (1870-1935)

<table>
<thead>
<tr>
<th>Country</th>
<th>List of main sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Czech Lands</td>
<td>1841 (Schnabel, 1848), 1934/1935 (Ceskoslovensky urad statisticky, 1936);</td>
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<tr>
<td></td>
<td>1863-1910 stats (Österreichische Statistik, n.d.)</td>
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<tr>
<td>Denmark</td>
<td>Produktionssstatistik, several issues, Erhverstaellingen 1935; Danmarks Mejeri-</td>
</tr>
<tr>
<td></td>
<td>Drifts-Statistik, Sveistrup, P. and R. Willerslev (1945)</td>
</tr>
<tr>
<td>Portugal</td>
<td>Informações de Estatistica Industrial (1861-1865) - Coimbra, Leiria, Aveiro,</td>
</tr>
<tr>
<td></td>
<td>Funchal, (1910-1913) Boletim do Trabalho Industrial: 50,53,53, 63.64, 65, 66,</td>
</tr>
<tr>
<td></td>
<td>Inquérito Industrial 1881, Inquérito Industrial 1890, Estatistica Industrial 1943,</td>
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<td></td>
<td>Costa (1946).</td>
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<tr>
<td>Sweden</td>
<td>“Bränsleförbrukingen åren 1913-1917”; SOS, Industri, several issues</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Royal Coal Comission 1871, Census of Production, 1907, 1924 and 1935</td>
</tr>
</tbody>
</table>
4. Preliminary results


The preliminary analysis of energy intensity (energy consumed per 1 ton of physical output) shows some interesting results (see Figure 1). Sugar and pig iron, some of the staple goods of the first industrialization show remarkable rates of energy intensity declines, and very little cross-country variations by 1935. This motivates the need to further analyze whether the role of foreign trade could have had an impact on the convergence in energy productivity. There are two major mechanisms which could potentially affect the energy productivity of a manufacturing sector between trading countries (Wan et al., 2015). First, increased involvement in foreign trade may reduce the productivity gaps due to technology diffusion and equalization of factor prices (Wan et al., 2015). On the other hand, the international specialization and division of labor may lead to growing differences in productivity levels (ibid).

On the other hand, textile goods (woolens and cottons) show very little change in energy intensity over the period of study. As already mentioned in the method section, this may to some extent be a result of the use of physical quantities, as quality differences cannot be considered in this measure. At the same time, the textile sector may be less suitable to improvements in energy productivity as is the sugar and pig iron production which is likely to benefit more from industry and unit scaling. Lastly, beer and cement production, although some of the more important sectors though with a far lower importance for trade, show a less pronounced declining trend in energy intensity.

Figure 1. Historical estimates of energy intensity (GJ/ton) of major industrial processes
4.2. Comparison of labor productivity and energy productivity trends (1913-1935)

Although more research has to be done especially on additional productive sectors as well as the year 1870, a clear trend emerges in labour productivity. If we compare the dispersion of labor and energy productivity (Table 2), it is also clear that energy productivity shows far lower disparities in cross-
country comparisons than is the case of labor productivity. For the production of pig iron, for example, the energy productivity gap between the most and least efficient country in our sample was just 113% in 1913. This indicates that the most efficient country was able to produce a bit more than twice as much pig iron by through the application of the same amount of thermal energy as the least efficient country. Although this may seem like a significant difference, the labor productivity gap in the pig iron smelting was far larger. This could be interpreted that the least efficient country had to employ 26 times as many workers for the same output as the most efficient country. It is also interesting, and especially once the 1870 data are added, to compare the development of this pattern across time. For the two benchmark years, for which we have currently data, the average dispersion of energy productivity (thus the productivity gap in cross-country energy use) has not changed substantially and remains far below that of the labor productivity. Simultaneously, there are some signs of declining differences in labor productivity by 1935. It remains to be researched to what extent the increased deployment of new electric motors was the primary driver of labor productivity gains but also cross-country convergence. Previous research found effects of electrification on both labor productivity as well as energy productivity, though this paper points to some very interesting and large differences in the absolute levels. In fact, it seems that technological innovation to a larger degree focused on labor-augmenting technologies rather than energy-saving machinery. With constantly rising labor productivity, wages were increasing and this may have initiated further search for labor-saving methods. In case of energy, on the other hand, energy prices and importantly its share in the total factor costs, offered less motivation to innovate. To be able to answer this, a more thorough analysis of cross-country differences in a number of factors and drivers may be necessary: energy prices, wages, investments, scale effect, trade openness and specialization.

Table 2. Comparisons of average dispersion in labor productivity and energy productivity in various productive sectors

<table>
<thead>
<tr>
<th></th>
<th>1913</th>
<th>1935</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Labor productivity</td>
<td>Energy productivity</td>
</tr>
<tr>
<td>Beer</td>
<td>82%</td>
<td>92%</td>
</tr>
<tr>
<td>Butter</td>
<td>308%</td>
<td>8%</td>
</tr>
<tr>
<td>Industry</td>
<td>Sugar refining</td>
<td>Cement production</td>
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<tr>
<td>------------------------</td>
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</tr>
<tr>
<td></td>
<td>6370%</td>
<td>47%</td>
</tr>
<tr>
<td></td>
<td>137%</td>
<td>46%</td>
</tr>
<tr>
<td></td>
<td>402%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>14%</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>58%</td>
<td>148%</td>
</tr>
<tr>
<td>Average std. deviation</td>
<td>1421%</td>
<td>44%</td>
</tr>
</tbody>
</table>

Source: Own calculations

Note: Given values show the average dispersion of energy productivity and labor productivity between the most and least efficient country (e.g., the labor productivity of butter production was 758% higher in the most productive country as opposed to the productivity in the least efficient country, thus the USA in 1935 was able to produce 758% more butter than Czechoslovakia while using the same number of employees).
4.3. Energy/labor ratio of manufacturing processes (1870-1935)

Finally, we calculate energy use relative to labor for various productive sectors. This ratio, E/L, relates to the amount of energy used (GJ) per one industrial worker in the specific sector. The ratio can be calculated either with intensity measures or productivity variables:

\[
\frac{E}{L} = \frac{E_{st}}{L_{st}} = \frac{1}{L_{st}} \frac{E_{st}}{E_{st}}
\]

Where \( E \) denotes total energy consumption (GJ), \( L \) denotes labor (in number of workers), \( EI \) is energy intensity (GJ/ton), \( LI \) labor intensity (workers/ton) and inversely \( LP \) labor productivity (output-based, ton/GJ) and \( EP \) is energy productivity (output-based, ton/worker).

Thus, the results largely highlight which sectors experienced the largest growth in labor productivity in relation to its energy productivity. Following graphs (Figures 2 to 4) show the cross-country differences. The overall results of increasing E/L ratio does not come as a surprise. In fact, there are forces working simultaneously at both levels - the numerator as well as denominator in the E/L ratio. First, the energy losses associated with energy utilization decreased substantially within the period of study. This was not only due to the improvements in the thermal efficiency of the centralized steam engines which supplied mechanical power to all the machine tools. Efficiency improvements have also been achieved through the introduction of decentralized electric drives. Devine (1983) estimates that overall efficiency of overall electric motors system increased to a level of 10-12%, up from some 3-8% characteristic for the traditional stationary steam engines. Obviously, those efficiency changes had a profound impact, but large achievements have been made also in the labor productivity. Particularly, after 1920 the rapid increase in labor productivity is likely to have a large impact on the E/L ratio in 1935.

The two sectors which experienced the most significant change in the energy/labor ratio are the production of pig iron and cement. This does not come as such a surprise, as both materials presented the backbone of modern infrastructures during the first industrialization. Economies of scale and the growing demand for iron and cement increased significantly not only the labor productivity but led to
some technological breakthroughs and energy saving. In fact, it is demand for these two materials which is most likely to increase in future, due to the construction of highways and buildings in the developing world of today (Smil, 2014). Concrete and steel enforcing bars are core materials of today’s industrializing countries as was the case of the Western world 150 years ago; China has poured as much cement into its roads over the past 3 years, as the USA has done throughout the whole 20th century (Smil, 2014). Of the other production processes analyzed a relatively significant increase in ratio of energy/labor was found in the sugar refining sector and also in the production of paper and pulp (although more data is needed in order to confirm this). Interestingly, all other producing sectors recorded only a moderate increase in energy/labor ratio within the period of study. One could argue here, that it is predominantly the standardized and uniform goods which experienced the largest rise in the E/L ratio. Theoretically, it would be those sectors which could increasingly benefit from technology transfer and upscaling at the unit as well as market level and thus increase substantially its labor productivity.
Figure 2. Annual energy consumption per labor in food and beverages
Figure 3. Annual energy consumption per labor in the production of consumer goods
Figure 4. Annual energy consumption per labor in the production of capital goods
Sources


Ceskoslovensky urad statisticky, 1936. Zpravy statniho uradu statistickeho republiky ceskoslovenske.


Devine, W.D., 1983. From Shafts to Wires: Historical Perspective on Electrification. J. Econ. Hist. 43,


