Machines, Energy and Economic Growth

Energy Capital ratios in Europe and Latin America

1875 - 1970*

Rick Hölsgens[1], Cristián Ducoing[2], Mar Rubio[3], and Ben Gales[1]

[1]Faculty of Economics and Business, University of Groningen,
h.n.m.holsgens@rug.nl , b.p.a.gales@rug.nl
[2]Department of Geography and Economic History, Umeå University,
cristian.ducoing@umu.se
[3]Department of Economics , Public University of Navarra ,
mar.rubio@unavarra.es

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Abstract

The relationship between energy and capital is one of the most important relationships of modern economic growth. Machines need energy to produce all the goods we enjoy; energy without machinery is useless. However, the great majority of the economic models do not take into account the elasticities of substitution (or complementaries) between these two main variables. Actually, energy is absent in many growth models and discussions on diverging economic development paths. We approach this relevant issue from a new perspective: energy and capital relations during 100 years. We use the latest estimations of capital stock (machinery and equipment) and energy consumption for Latin America and compare them with those of Western Europe. The energy capital ratio (how much energy is used per unit of capital) could be a predictor of economic growth, thus providing some answers about the timing and causes of the different modernisation patterns of these regions and showing us some answers about the long run relationship between energy consumption and capital accumulation.

Keywords: Capital stock, energy, energy efficiency, Latin America, Europe.

JEL Codes: N70, N10, O33, Q43.

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1 Introduction

Economic growth models, building on Abramovitz (1956) and Solow (1956), tend to stress the importance of human and physical capital accumulation (Leimbach et al., 2015; Mankiw et al., 1992). While there are limits to the extent in which labor can grow, capital-deepening (i.e. increasing capital per worker) makes enhanced growth possible. Energy is a crucial input for both labor and capital. Both labor and capital can convert energy into useful work. "But the ceiling for the energy employed directly by labor is the food that can be consumed by each worker. Capital has no such ceiling, or only that imposed by current technology. Thus, in the nineteenth century, capital-deepening production tended to mean energy-deepening production too" (Kander et al., 2013, p. 220).

With initial industrialization, energy-deepening (especially of modern energy carriers) is to be expected, however as argued by Kander et al. (2013, pp. 219–221) and Allen (2012) capital-deepening was the most important driver for increasing outputs. In this paper we focus on the interrelation between energy and capital and examine the divergent histories of Western Europe and Latin America. We cover the period 1875-1970 and argue, supporting our ideas in recent energy history research by Csereklyei et al. (2016) and Kander et al. (2013), that the rapid decrease in energy-capital ratios in Europe both growth rates and levels, as compared with Latin America, can help to understand their economic divergence.

Latin American countries began their independence with vast endowments of land and natural resources, and were for a while, more prosperous than some European nations. Nevertheless, over the course of the nineteenth and twentieth century, Latin America did not manage to maintain its position and a divergence between Europe and Latin America emerged (Bértola and Ocampo, 2012). Measures of GDP per capita have shown the increasing divergence in output per capita between Latin America and Western Europe (see table 1).

There have been several studies to measure and explain these differences[1]. Both physical capital stocks (Tafunell and Ducoing, 2015) and energy consumption (Yáñez et al., 2013; Rubio et al., 2010) have been used as proxies for economic development, and as explanations for the divergence. In this article we look at the ratio between energy and capital. We argue that the rapid decrease in energy-capital ratios in Europe in the twentieth century, as compared with Latin America may help to explain differences in economic development as it is illustrative of technological advancements and efficiency increases (i.e. less energy is required to produce economic output). In section two we explain the theory behind the relation between energy and capital, in section three we show the data used in this research, section four presents the results of the comparison and section five concludes.

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[1] See for example Bulmer-Thomas (2003), Maddison (2007)

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Table 1: GDP per capita in several years

	1875[2]	**1913**	**1929**	**1950**	**1970**
Belgium	2.861	4.220	5.054	5.462	10.611
France	1.876	3.485	4.710	5.186	11.410
Germany	1.839	3.648	4.051	3.881	10.839
Italy	1.542	2.564	3.093	3.502	9.719
Netherlands	2.755	4.049	5.689	5.996	11.967
Portugal	975	1.250	1.610	2.086	5.473
Spain	1.207	2.056	2.739	2.189	6.319
Sweden	1.345	3.073	4.145	6.769	13.011
UK	3.190	4.921	5.503	6.939	10.767
Argentina	1.417	4.038	4.610	5.276	7.730
Brasil	691	694	968	1.559	2.871
Chile	1.233	2.836	3.279	3.741	5.120
Colombia	527	786	1.447	2.042	2.956
Mexico	623	1.528	1.602	2.308	4.382
Uruguay	1.833	2.694	4.273	4.873	5.124
Venezuela	544	1.184	3.040	5.201	9.399

Source: Bolt and van Zanden (2013) for Europe and Bértola and Ocampo (2012) for Latin America

2 Energy-capital ratios as indicator of economic development

Before we can discuss the Em/Km&e ratio as an indicator of economic development, it is important to first address the roles of both energy consumption and capital accumulation separately. The relationship between energy and economic development is complex. Csereklyei et al. (2016) find, not surprisingly, that energy use per capita increased over time as incomes grew; even though there might be some 'decoupling' in developed countries in recent years and the energy intensity (E/GDP) of European countries declined over the last two centuries (when traditional energy sources are included) (Gales et al., 2007; Kander et al., 2013). The Industrial Revolution is often linked with the increasing usage of energy (in particular coal), but whether coal consumption sparked the Industrial Revolution, or whether it was mainly a consequence of economic development is still subject of debate as we can see in the first chapter of (Allen, 2009) and McCloskey (2010, Chapter 22). The question of causality between energy consumption and economic development is still contested and is still subject of debate (Liddle and Lung, 2015; Payne, 2010). According to Kander et al. "energy consumption, and the availability of coal, helped propel economic growth (as did other things). Consumption of coal seems to have been a key part of economic success (. . .) and cheap energy was a necessary condition of the industrial revolution" (Kander et al., 2013, p. 209, original emphasis). They argue nevertheless that capital-deepening was the most important driver for increasing outputs.

In a Cobb-Douglas production function where output is a function of labor and capital there are limits to the extent in which labor can grow, capital-deepening makes enhanced growth possible. De Long and Summers (1991), for instance, have argued that there is a strong causal relationship between investments in equipment and economic growth[3]. However, for machinery and equipment to produce output and economic growth, input of energy is required.

Nonetheless, over the long run, the ratio between capital stock and energy consumption changed notably. Kander et al. (2013, p. 338) present trends for Sweden, Spain and Britain and conclude that in all three of these countries the energy to capital ratio decreased notably[4]. The extent to which this ratio changed is not the same in all countries and depends a lot on the initial levels of both capital stock and energy consumption, but an overall trend towards relatively less energy input per unit of capital is clear. As the energy capital ratio informs us about the amount of energy needed per unit of capital, a decreasing trend signals energy efficiency improvements.

Energy is a crucial input for economic growth through its direct relationship with the productivity of both labor and machinery; without energy no production hence no economic development. However, thermal efficiency of machinery and equipment has increased over the years (Ayres and Warr, 2009) and also the economic efficiency of energy conversion has increased (at least in the West) (Kander et al., 2013; Gales et al., 2007). This means relatively, less energy is needed to produce the same output. Kander et al. (2013, 2013, appendix A)[5] present a growth accounting model which incorporates energy; they show how energy quantity, quality and augmentation (i.e. energy saving biased technological change) contribute to economic growth. Stern and Kander (2011) find that especially during the Industrial Revolution expansion of energy services was a major factor in explaining economic growth (for the case of Sweden), but later capital and labor-augmenting technological change becomes the dominant factor.

In other words, when energy is scarce it can be a constraint on economic growth (i.e. the pre-IR 'Malthusian' steady state), but once energy is relatively abundant (i.e. make up a smaller cost-share) capital becomes increasingly more important (Stern and Kander, 2011). This, it could be argued, is in line with the at first sight, controversial finding of Bretschger (2015) that increasing energy prices are beneficial to economic growth. Bretschger argues, based on a data set which starts in 1975, that increasing energy prices spur innovation, and that these additional investments foster long-run economic growth. With the emergence of industrialization, the consumption of (modern) energy sources may be expected to rise, but investments in new, modern, more energy-efficient machinery and equipment will be crucial for long-term economic development. As the energy-capital ratio captures the consumption of energy relative to the accumulation of capital a decreasing energy-capital ratio signals economic progress through investment in higher quality capital. This claim finds support in existing data for the more recent period: countries with lower energy-capital ratios tend to be richer than countries with a high energy-capital ratio (see figure 1).

This graph does not show trends over time, but it does suggest a correlation between the energy-capital ratio of a country and its economic performance: lower E/K-ratios by and large correspond with higher

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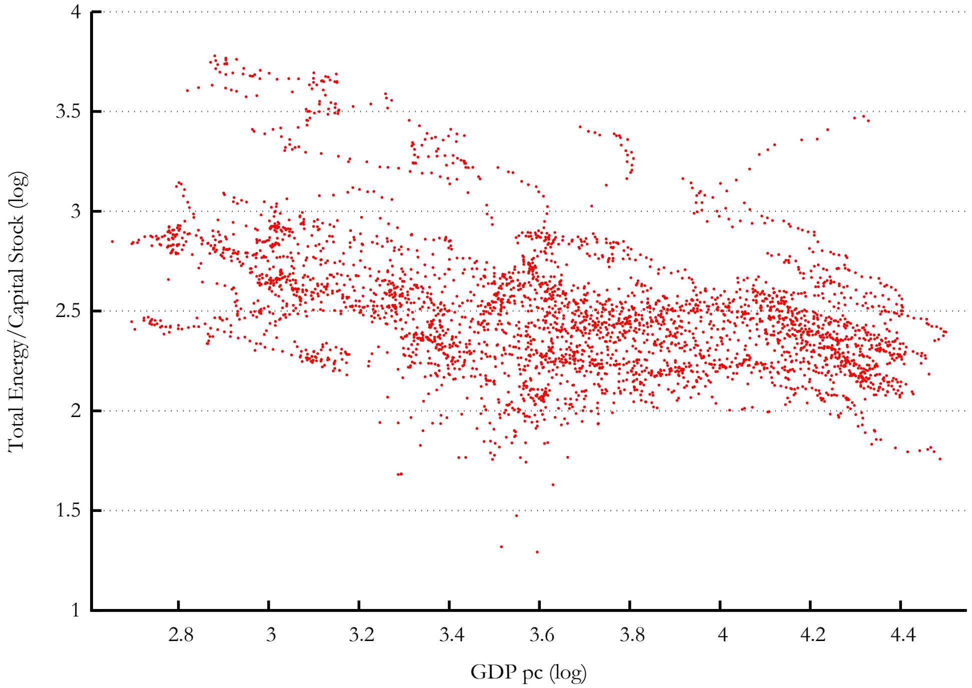
[3] In their 1993 extension of the 1991 paper they confirm this relationship especially for developing countries (De Long and Summers, 1993). In this same line, is worth to mention the article by Delong (1992), about the relationship between equipment investment and productivity in the long run

[4] Notice that Kander et al. speak of the capital to energy ratio (K/E), hence they speak of increases in the K/E ratio, rather than its reverse.

[5] Based on Stern and Kander (2011)

Figure 1: Energy/Capital vs. GDP per capita. 99 countries over the period 1971 - 2010



Sources: Capital Stock Groningen Growth and Development Center. FebPwt - penn world table - international comparisons of production, income and prices (8.0); GDP per capita The Maddison-Project, Maddison update 2013. Accessed May 19th and Energy Consumption Cssereklyei et al. (2016).

per capita income (the observations in the top-right of the graph mainly correspond with oil producers). Csereklyei et al. (2014) cover the period 1971-2010 and find that, at least for rich countries, E/K ratios declined, in line with the findings by Kander et al. (2013). Interestingly though, they found increasing E/K ratios in "many developing countries, particularly in Africa and in Latin America" (Csereklyei et al., 2014).

As we believe decreasing E/K ratios signal economic development through efficiency increases, the reversed trends for these developing countries may be reason for concern.[6] It also opens up the question: Is this divergence between, in our case, Europe and Latin America a structural, long-term, phenomena? After all, Kander et al. (2013) stress that the emergence of less energy intensive information and communication technologies (since the 1970s) caused a break in the trends towards quicker decreases in the European countries they compared. Given that Warr and Ayres (2012) found that, before the rise of ICT, *exergy* can largely explain the Solow-residual, we only focus on the period up to 1970[7].

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[6] Increasing energy-capital ratios in developing regions is a reason for concern as it may hamper their economic development, but it is also a reason for environmental concern. If these developing regions (Latin America, but also other regions not included in the current study, such as South-East Asia and China) realize catch-up growth only based on capital-deepening without improving their energy efficiency, their economic development will be unnecessarily energy-intensive and thus emission-intensive.

[7] Warr and Ayres find that after the 1970s exergy is no longer the sole explanation for TFP, the ICT-revolution introduced a new factor in the form of information to changes in total factor productivity

3 Data

The E/K ratio we have been discussing so far (in the theory and empirical findings of Kander et al. (2013); Kander and Schön (2007) and Csereklyei et al. (2014) applies to all energy consumption (modern and traditional) and to the entire fixed capital stock (i.e. capital in machinery & equipment, infrastructure and residential and non-residential constructions). Because of data limitations it is impossible to extent both time series back into the 19th century though. We therefore have to work with data on the consumption of modern energy carriers, and capital in machinery and equipment only. This has a number of important implications, as we will show below with the example of the Netherlands (a country for which we have all data for a long period), but before discussing these, we first introduce the data sources we use. Beyond the data limitations, the use of modern energy carrier is intrinsically linked with the existence of machinery and equipment to produce and transport goods.

3.1 Energy Data

Data availability, especially from the side of the Latin American countries, compels us to restrict our analysis to the use of modern energy carriers (i.e. fossils and modern renewable such as hydroelectricity). An obvious downside of this restriction is that, especially in the nineteenth century, traditional organic energy sources still made up substantial shares of the total energy consumption for many of our sample countries. The first consequence of this limitation is that the total energy consumption of a country will be underestimated and the further we go back in time, the more this will be the case. Since the share of modern energy sources in the total energy mix increases over the time, the second consequence is that the growth of energy consumption may appear larger than it actually was. Gales et al. (2007) have shown the importance of including traditional sources of energy to get a proper view on the historical trajectory of energy intensity. When only modern energy sources are included the energy intensity of European countries show an inverted U-shape, when also traditional energy sources are included, most countries show constantly decreasing energy intensities[8]. As the example of the Netherlands will also make clear, when a country is in transition from traditional to modern energy sources it may appear as if the energy consumption of the country is increasing rapidly, while in fact the increase is more gradual because of the substitution of modern energy carriers for traditional sources.

We sampled our energy consumption data from a number of sources. Firstly, we take the data on energy consumption in Latin America from Rubio et al. (2010) and Yáñez et al. (2013). For a number of European countries, country specific energy consumption series have been published: Italy (Malanima, 2006), Netherlands (Gales et al., 2007), Portugal (Henriques, 2011) Spain (Rubio, 2005)[9] and Sweden (Kander, 2002), and the UK (Warde, 2007); for the additional European countries (Belgium, France and Germany) we use unpublished data collected by Ben Gales.

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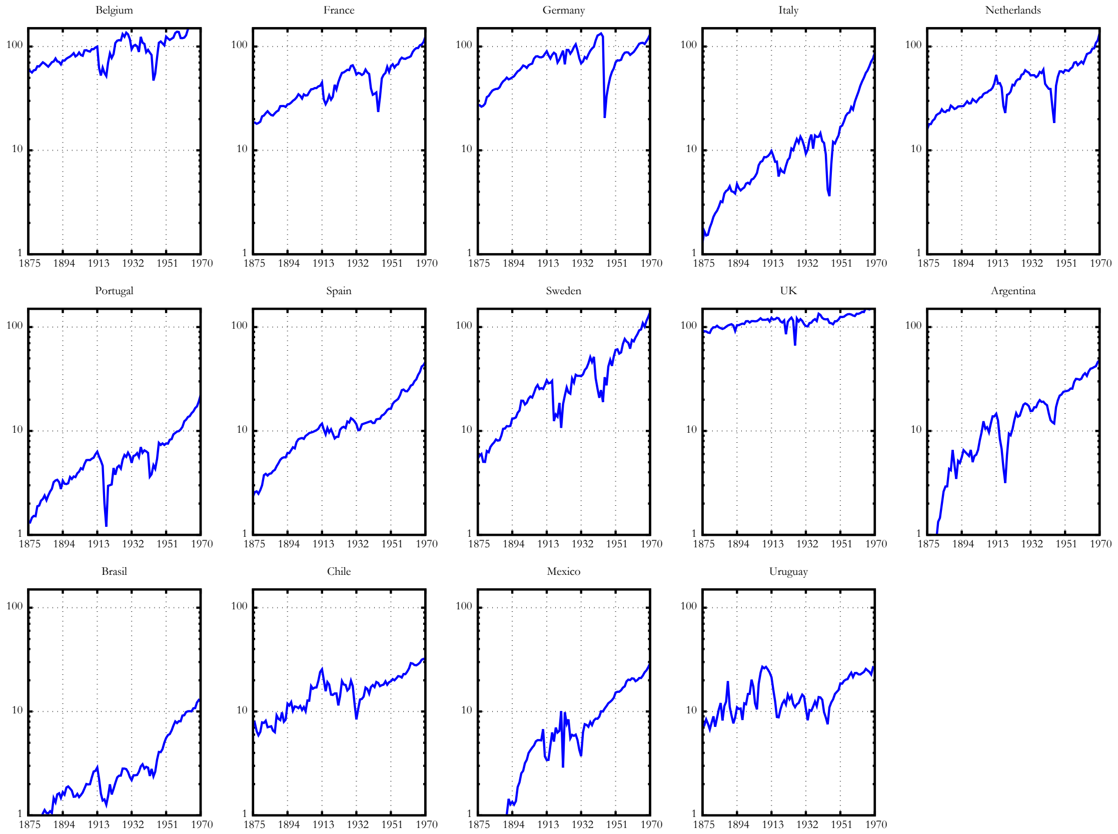
[8] See also Kander et al. (2013, fig. 10.11 & 10.12); the only noteworthy exceptions are the UK and Germany at the height of their industrialization.

[9] we use the most recent and revised data Gales et al. (2007)

Table 3.1 presents the consumption of modern energy (i.e. fossil fuels and electricity) in the respective countries per capita. Both total energy consumption as well as energy consumption per capita grew for all countries up until the energy crises of the 1970s. With the exception of Spain and Portugal, the European countries overall used many times more energy per capita than the Latin American countries in our sample. Chile and Uruguay stand out as Latin American countries with relatively high energy consumption per capita in the late nineteenth century, however, whereas the energy consumption in most countries increased throughout the twentieth century, energy consumption per capita stagnated in these countries in the mid-twentieth century[10].

Figure 2: Energy Consumption in Peta Joules. Several countries 1870 - 1970



3.2 Capital stock in machinery and equipment

Several scholars have done research on capital stock formation to provide estimates for Europe (e.g. Maddison (1994). For Latin America, the main research has been elaborated by Hofman (2000) and Tafunell and Ducoing (2015). For data on capital stock we run into comparable data limitations we also faced for energy. Also here, especially the Latin American data compels us to restrict ourselves to one part of the capital stock:

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[10] The UK shows a similar trend in per capita consumption, as Britain was the workshop of the world in the late nineteenth century, this is less remarkable.

Table 2: Energy consumption (in TJ) per 1000 inhabitants

	1875[11]	**1913**	**1929**	**1950**	**1970**
Belgium	59,88	99,76	135,94	102,71	189,1
France	18,59	45,04	65,10	57,07	123,9
Germany	27,12	90,11	105,07	61,83	131,5
Italy	1,29	9,87	13,55	13,96	86,9
Netherlands	15,91	53,11	59,17	55,95	134,1
Portugal	1,32	6,32	5,64	7,33	22,1
Spain	2,35	25,13	27,01	26,63	46,2
Sweden	5,43	30,73	34,74	52,38	139,2
UK	92,70	122,84	119,11	118,40	160,0
Argentina	0,69	14,64	18,40	23,79	48,1
Brasil	0,96	2,89	2,79	5,02	12,5
Chile	7,30	25,53	19,80	19,17	31,4
Colombia	0,22	0,14	1,92	5,36	9,8
Mexico	0,06	3,41	5,99	13,60	29,1
Uruguay	7,37	21,42	13,39	16,13	26,1
Venezuela	0,03	0,40	5,80	32,45	66,5

Sources: Energy Gales et al. (2007); Rubio et al. (2010); Population Bértola and Ocampo (2012); Bolt and Van Zanden (2014)

machinery and equipment. This also has some serious implications for our analysis. First of all, the heating (or potentially cooling) of buildings requires energy as well which we cannot take into account in the current analysis. Second, machinery tends to increase more than other capital (Kander et al., 2013, p. 30). This means that, when dividing energy consumption by capital in machinery and equipment, the changes over time will be more pronounced than the findings of Kander et al., who divided energy consumption by total capital stock.

The study of the capital stock in the developed world has been a recurrent research topic. The seminal works of Goldsmith (1951), Kuznets (1961) and Feinstein (1972, 1988) have provided a reference for subsequent studies conducted on many industrialized countries. The most common way to estimate the capital stock is the Perpetual Inventory Method (PIM) which consists of the weighted sum of past investment flows. The gross stock is calculated by adding the cumulative year-to-assets and subtracting totally worn (withdrawals).

To calculate the gross stock in year t we follow Feinstein (1988)

1.) $GFCS_{t-1} + GFCF_t - Rtr = GFCS_t$

Where $GFCS_{t-1}$ is the stock of year $t-1$, $GFCF_t$ is fixed capital formation in the current year (t) and Rtr are capital withdrawals produced in the current year. The net stock is obtained by subtracting the gross stock depreciation, which is expressed in mathematical terms as follows:

2.) $NFCS_{t-1} + GFCF_t - \delta - \delta(Rtr) = NFCS_t$

Where $NFCS_{t-1}$ is the net capital stock at the beginning of year t, $GFCF_t$ is the gross fixed capital formation during the year, δ is the depreciation during the period, $\delta(Rtr)$ are depreciated capital goods removed during the year t and $NFCS_t$ is the net capital stock at the end of period t.

The PIM requires two masses of information: historical series of GFCF at constant prices, for each type of asset and the capital stock in the initial year(OECD, 2009). The latter can be derived directly from the first mass of information, when you set the initial year in the terminal year of life of the first generation of assets with the greatest longevity. For example, with respect to the nineteenth century, if we attribute a life of 50 years to non-residential buildings and we have investment series dating back to 1850, the initial year of the aggregate capital stock is 1900. This is precisely the option we have chosen. Upon calculation of the capital stock in equipment only the initial year of the stock goes back to 1875, on the assumption that, during that period, the life of these assets was 25 years. In Maddison historical series of productive capital accumulation (non-residential capital) were published for six developed economies: Germany, France, UK, Japan, USA and the Netherlands. The data are estimates are half-year, considering the accumulated investment as the expected life of the relevant assets. We used from this study the data of Germany, France and UK and we replicated the methodology for the rest of the countries. The data sources for the other European countries were: The Netherlands (Albers, 1998; Groote et al., 1996), Sweden (Schön and Krantz, 2012), Belgium (Van Meerten, 2003), Italy (Toniolo, 2013), Portugal (Gomes da Silva and Lains, 2013)), Spain (Prados de La Escosura and Rosés, 2010).

For the case of Latin America, estimates of capital stocks have been elaborated by Tafunell and Ducoing (2015) for Argentina, Brazil, Chile and Mexico. Also, there are series available in Tafunell (2009); Tafunell and Ducoing (2015) to expand the capital stock estimates to other Latin American countries[12]. In this paper, we have done the capital stock estimation in the same way for the countries that were not included in Tafunell and Ducoing (2015).

Table 3: Capital stock in machinery & equipment per 1000 inhabitants

	1850	**1875**	**1913**	**1929**	**1950**	**1973**
Belgium			2144[a]	2.328	2.883	6.036
France					1.075	5.009
Germany					1.222	5.335
Italy		237	1.306 [b]	702	1.757	5.643
Netherlands	371	525	1.685	2.416	2.216	7.742
Portugal						
Spain		214 [c]	356	650	682	3.052
Sweden	49	136	751	1.188	4.309	12.311
UK			858	1.416	2.132	5.642
Argentina			364	371	639	1.614
Brasil			681	602	571	747
Chile			504	626	479	725
Colombia						
Mexico			180	237	553	1.948
Uruguay	356[d]		180	237	553	1.948

[a] data for 1914
[b] data for 1935
[c] data for 1890
[d] data for 1884

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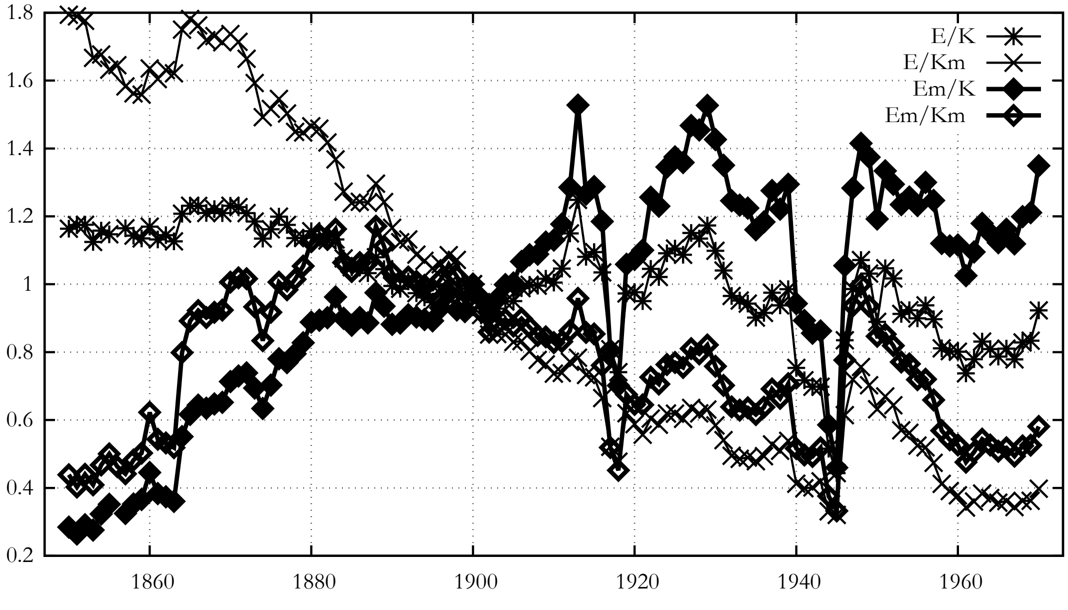
[12] For an analytical description of the long-term evolution of GFCF in Latin America, see Tafunell (2013)

We can observe huge differences in capital stock in machinery & equipment, both within the regions and across them, especially at the end of the period (see table 3). Up until the 1950s, the Latin American countries, and most notably Uruguay, can keep up with the European countries. Between 1950 and 1973 the European countries increased their capital stock roughly by a factor of 3-5; the only Latin American country that comes close to this is Mexico. However, if we observe the long run, this situation was different before the First World War. Chile, for example had US$ G-K 504 in machinery per 1000 inhabitants in 1913 and Sweden has just 1,5 times more. If we jump to 1970 this differences has changed to a ratio of 17 (to Sweden).

3.3 Implications of our data choice: the example of the Netherlands

As mentioned above, the usage of modern energy sources rather than total energy and the usage of capital stocks in machinery and equipment rather than total capital stocks has a number of consequences that limit the comparability of our analysis with the findings of Kander et al. (2013) and Csereklyei et al. (2014). Therefore, before presenting the results of our analysis we first work out the case of the Netherlands by way of example. For the Netherlands we have long-term time series on all relevant variables: modern energy consumption, total energy consumption, total fixed capital stock (K), and capital in machinery and equipment. Even though machinery and equipment was, especially in the earlier stages of industrialization, the most important aspect of capital-deepening (Kander et al., 2013) it is only a subset of all capital. Other forms of capital require energy as well, for example for heating or cooling of houses and office buildings. Unfortunately we cannot divide energy consumption among these different forms of capital for lack of disaggregated data. Figure 3 shows what happens when we use modern energy sources only, and what the result is of the use of machinery and equipment rather than total capital stocks.

Figure 3: energy-capital relations in the Netherlands, 1850-1970 (1900=1)



Sources: energy data: Gales et al. (2007); capital data: Albers (1998) and Groote, Albers and De Jong (1996)

As figure 3 shows, if we look at the ratio between total energy consumption and all capital, we see an overall decrease over this period, although it is less pronounced as the findings for Spain, UK and especially Sweden Kander and Schön (2007). There are two important reasons for this. First of all, the Netherlands started with relatively high levels of capital. Second, the Netherlands transformed into a rather energy intensive country during the 1960s; therefore the E/K ratio increases again at the end of our period (after the 1970s it also decreased again)[13]. During most of the nineteenth and twentieth century attempts to economize on fuel were the norm though (Ayres et al., 2003). This can also be seen from the ever decreasing energy intensity levels documented by Gales et al. (2007). They found that according to their new series, "energy intensity tends to decrease, except during the 1950s and 1960s: a period of fast economic growth and very low energy prices" (Gales et al., 2007, p.236). However, overall, the decrease is noticeable.

If we, instead, limit the capital stock we take into account to machinery and equipment, the decreasing trend becomes a lot more visible. The main reason for this is that in the mid-nineteenth century, the Netherlands was still relatively non - industrialized, so the accumulation of capital in the form of machinery and equipment went a lot quicker than the accumulation of other forms of capital. By looking only at machinery and equipment we therefore capture investments in this more productive form of capital, and see more clearly an increase of efficiency. Since we do not know exactly how much of the energy was exactly used to power these machines, and how much was used for other purposes (such as heating) this decrease may well exaggerate the efficiency improvements though.

Besides using a subset of all capital, we also use a subset of all energy consumed, namely modern energy only (Em). Let us first see what the effects are of considering only modern energy sources (in this case excluding peat), but all accumulated capital (Em/K). Now, we no longer see a declining trend, but rather a weak U-shape. Since the share of modern energy carriers in the entire energy system increased rapidly in the nineteenth century, this is not surprising. As in the twentieth century, and especially after the Second World War, virtually all energy was derived from modern sources, the green and blue line are essentially the same (because 1900 is set to 1 the deviations in the green line appear somewhat more pronounced, the decreasing path is entered much later because of the substitution of modern energy for traditional sources that was still taken place before WWII).

Finally, we arrive at the energy capital ratio we are using in this paper: modern energy over capital in machinery and equipment (Em/Km&e). Here we see the increasing trend caused by the transition to modern energy sources in the nineteenth century, but then a decrease during the twentieth century. We see that after WWII, energy consumption increased rapidly, while the accumulation of capital in machinery and equipment initially remained slightly behind, but the downward trend is quickly continued until the 1960s when the discovery of domestic natural gast boosted energy consumption[14].

What does this exercise tell us about the comparability of our indicator with the indicators used by Kander et al. (2013) and Csereklyei et al. (2014)? And what does it mean for the international comparison

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[13] The post-Second World War boom in energy consumption was a historical anomaly. During this period, characterized by Pfister with the 1950s syndrome, energy seemed to be available in unprecedented and unlimited supply (Pfister, 2010)

[14] Figure 3 represents the Modern Energy/Machinery&Equipment ratio in a longer period)

in the remainder of this paper? Firstly we have to observe that focusing on machinery and equipment means that we may expect a more pronounced decreasing trend because the accumulation of machinery and equipment speeds up with economic development and goes quicker than the accumulation of other forms of capital (i.e. industrialization, see Kander et al. (2013)). Secondly, the exclusion of traditional energy means though that we might expect an inverted U-shape, especially in countries where the transition to modern energy carriers developed relatively late, and was still going on in the twentieth century. Nonetheless, over the long run, more industrialized/developed countries will still present a decrease in the E/K ratio in the more modern period. We may therefore expect that our findings for Em/Km&e, even though they might exhibit an increase in the earlier period, should show efficiency improvements through eventual decreases.

4 Results

We have done an index (UK 1890 = 100) to understand the trends of the several countries of our study. This index will be the base to calculate the growth rates on the total period and the sub - periods. A graphical explanation of these index it could be appreciated in figures 4 and 5. One of the interesting results of this exercise, is to appreciate in the long run the differences between Europe and Latin America. Also, we can classify intra regions. If we compare the growth of the period 1875 - 1970, we obtain three groups of countries. The decreasing growth rates group, the stable growth rates group and the increasing growth rates group. The first groups comprises Netherlands, Spain, Sweden, UK, Chile and Uruguay; the second group comprises Argentina; and the last one comprises Italy and Brazil . These results are changing in function of the chosen period. If we decide to use the year 1930 as starting point, the groups change dramatically.

Table 4: Growth rates Modern Energy/Capital in M&E

	1875 - 1970	**1890 - 1970**	**1900 - 1970**	**1930 - 1970**	**1950 - 1970**
Belgium			-0,005[a]	-0,008	-0,117
France				-0,048	-0,048
Germany	-0,006 [b]		-0,016	-0,034	-0,040
Italy	0,009	0,006	0,005	0,003	0,028
Netherlands	-0,007	-0,007	-0,005	-0,005	-0,027
Portugal			-0,037[a]	-0,037	-0,028
Spain	-0,010	-0,010	-0,010	-0,013	-0,027
Sweden	-0,017	-0,023	-0,024	-0,026	-0,008
UK	-0,024	-0,026	-0,026	-0,024	-0,039
Argentina	-0,004	-0,004	-0,005	-0,016	-0,016
Brasil	0,010	0,018	0,020	0,034	0,039
Chile	-0,012	-0,004	-0,001	0,004	0,009
Mexico	0,012	-0,005	-0,016	-0,020	-0,041
Uruguay	-0,016	-0,016	0,008	0,002	0,024

[a] 1914 - 1970

[b] 1880 - 1970

Figure 4 and 5 and table 5 show the Em/Km&e ratios for the European and Latin American countries respectively. We see that the rate of the decline (i.e. the steepness of the curves) may differ substantially; this is related to both the initial levels of capital and the energy intensity (E/Y) of the economies. There is a clear difference in the trends though. While most European countries show decreasing Em/Km&e ratios in the twentieth century, the Latin American countries exhibit more mixed results.

The Netherlands, Sweden and Spain, show an initial increase in their respective Em/Km&e ratios in the end of the nineteenth century. Given that these countries were relatively late industrializers within Europe whose energy system switched to coal later, this is exactly what we would expect. However, just as the UK, which had made a more complete transition to modern energy carriers much earlier, and Portugal, for which our data start a bit later, they all witnessed a decrease in the energy capital ratio, and thus signal efficiency improvements, throughout the twentieth century.

Belgium is somewhat more tricky. We see the decreasing $Em/Km\&e$ we would expect since the late 1920s. From the First World War until the late 1920s, the $Em/Km\&e$ ratio increased sharply though, however, as Belgium was heavily affected by the war, this can probably largely explain this anomal. For Germany and France, the available capital data limits our analysis to a too short period to derive any hard conclusions, but the downward trends we do see for the years available seem to be in line with the other European countries in our sample. The only European outlier is Italy.

In Italy, the transition to modern energy sources happened remarkably slowly. The share of traditional energy dropped just below 50% only just before WWII, while over the period 1914-1945 the growth rate of modern energy consumption was actually negative (Bartoletto, 2013). This explains the decreasing *Em/Kme* in the interwar period. After the Second World War, until the oil crisis of 1973, modern energy consumption (of especially oil) in Italy showed an growth rate of 17% per year (Bartoletto, 2013). Given this impressive rate of energy-deepening and the late transition to modern energy sources, the increasing $Em/Km\&e$ ratio after WWII can be explained, but Italy is a marked anomaly within the European countries.

The Latin American countries display very mixed results. Argentina does show signs of efficiency improvements. The very high energy-capital ratio of Chile in the late nineteenth century, on par, as the only country in our sample besides Portugal, with the UK, stands out, but can be explained by the very energy-intensive production of Saltpeter which took place there in the second half of the nineteenth century (**?**). Nevertheless around the turn of the century impressive capital-deepening also took hold. During the twentieth century, the Em/Kme ratio barely improved.

For the case of Mexico we see roughly an inverted U-shape in the way we have also seen it for the late industrializers in Europe. Mexico only peaked a few years later than the European countries, indicating a later uptake of modern energy carriers. Mexico was also the only country in our sample where import substitution industrialization did not take place. Although the country was behind on the European examples, it did develop its own machinery and exhibits comparable efficiency improvements.

Brazil showed very low Em/Kme ratios throughout most of the twentieth century, but they increased steadily since the First World War, only to accelerate after the Second; its late uptake of modern energy carriers has made the Brazilian case comparable to Italy. Uruguay, finally, appears to demonstrate an inverted U-shape until the 1950s, even though the Em/Kme ratio thus decreased for some decades, this decrease did not continue after the Second World War. As we saw in table 3, this is mainly the result of a sudden stagnation of the growth of the capital stock.

Figure 4: Energy Capital Ratios in Europe. 1875 - 1970 (UK 1890 = 100)

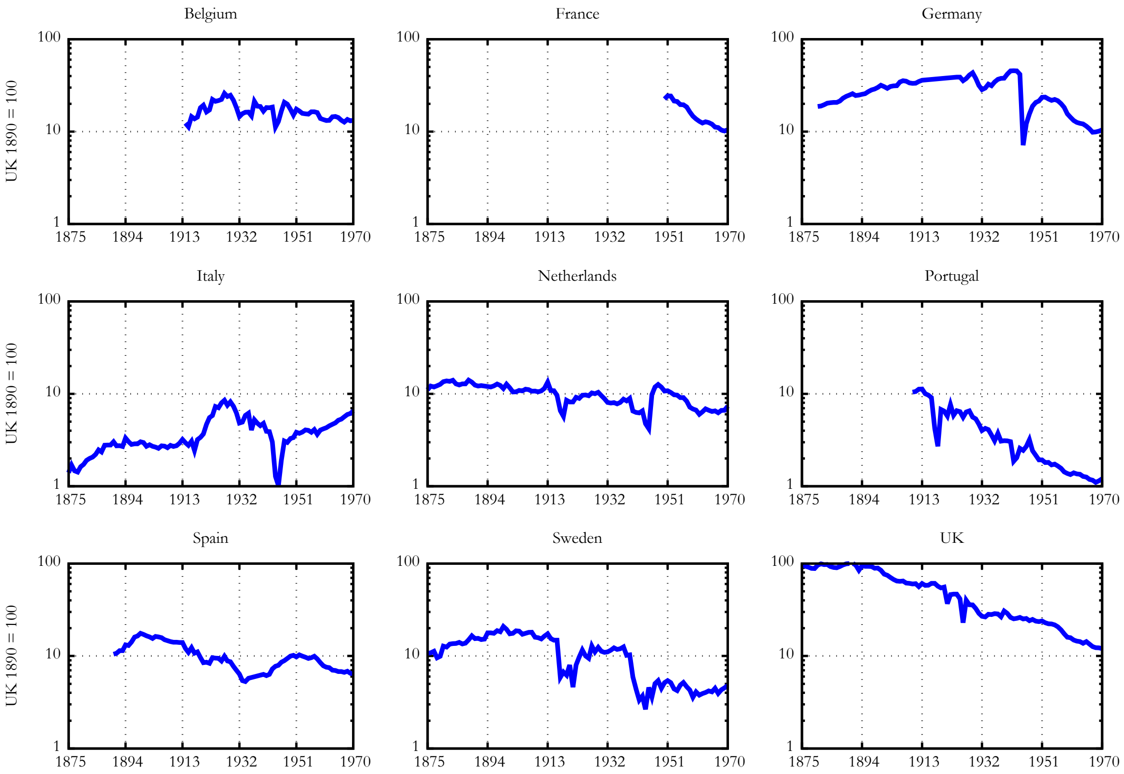
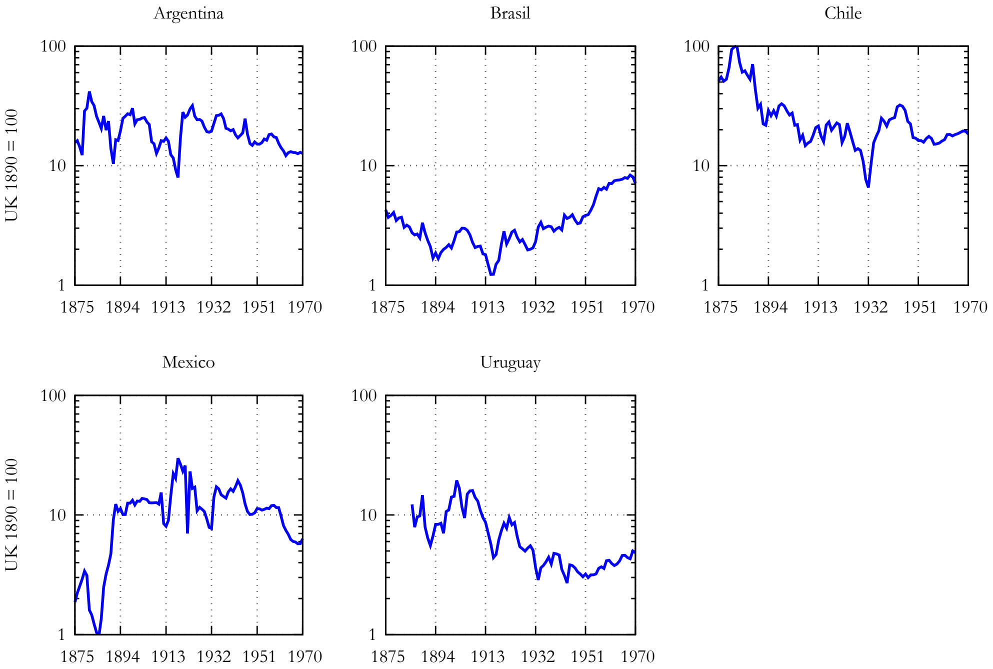


Figure 5: Energy Capital Ratios in Latin America. 1875 - 1970 (UK 1890 =100)



Overall we can thus confirm the findings of Kander et al. (2013) for the European countries, but although decreasing E/K ratios have been the norm in the more developed parts of the world, they did not occur in the developing region of Latin America. Secondly, we can also extend the findings by Csereklyei et al. (2014) and see that the divergence between Europe and Latin America is not only a result of the Third Industrial Revolution taking place since the 1970s. It is more structural. This has a number of implications: First, the structural backwardness of Latin America in terms of its energy efficiency hampers its economic development. The lack of efficiency improvements signals lack of innovation and a lack of investment in modern (i.e. more energy efficient) capital that could contribute to economic development. As Latin American countries grew their capital stock largely by importing second hand machinery and equipment from Europe (Tafunell and Ducoing, 2015), opportunities for catch up were also limited because of the constant backwardness in the efficiency of this machinery; as we saw, the only notable exception was Mexico, a country which did not follow a policy of import substitution industrialization and the only country with a 'modern' Em/Kme pattern.

We argue that decreasing Em/Kme ratios are important for economic development, but also signal economic development as they are also indicative of investment in new, more energy efficient, capital goods. When an investment in physical capital is made, i.e. the machine or infrastructure has been put in place, the energy consumption is more or less determined. In such a so-called putty-clay model, which tends to hold for energy consuming capital, richer countries can be expected to have invested more in higher quality, more energy efficient, capital. Hence a lower energy-capital ratio is indicative of more economic prosperity, while a decreasing E/K ratio over time is indicative of economic development. Whereas Western European countries managed to keep investing in new and better machinery, Latin America stayed behind and did not succeed in keeping up with the developments in the Western World, and therefore also entered a path of slower growth.

Table 5: Energy/Capital Stock in M&E Ratio (TJ per thousands M&E units)

	1850	**1875**	**1913**	**1929**	**1950**	**1970**
Belgium			29,1	58,4	35,6	31,3
France					53,1	24,7
Germany					50,6	24,6
Italy		3,3	7,0	19,3	7,9	15,4
Netherlands	12,5	26,1	25,6	24,5	25,2	17,3
Spain			66,2	41,5	39,1	18,2
Sweden	14,3	25,2	36,4	29,2	12,2	11,3
UK		230,2	136,8	84,1	55,5	28,4
Argentina		36,7	37,6	49,6	37,2	29,8
Brasil		10,0	3,5	4,6	8,8	16,7
Chile		120,5	41,7	31,7	40,0	43,3
Mexico		4,4	21,2	25,3	24,6	14,9

5 Conclusions

In this paper we compared the long-term trends in energy-capital ratios of five Western European and four Latin American countries. We found, following up on Kander et al. (2013) and Csereklyei et al. (2014), that the Em/Km&e ratios in the Western European countries, overall, decreased steadily over the course of the twentieth century (Italy being the only exception)[15]. Latin American countries show more mixed results, and stayed behind in this development. We covered the period 1875-1970 and argue that the rapid decrease in energy-capital ratios in Europe in the twentieth century, as compared with Latin America, can (in part) explain the economic divergence between the two regions. Decreasing Em/Km&e ratios signal investment in modern, more energy efficient, machinery. These investment can foster economic growth and build the bases for structural change and development.

Second, energy efficiency improvements are crucial for sustainable growth. Kander et al. (2013, pp. 339–341) make clear that capital cannot endlessly substitute for energy as a certain level of energy will always be needed to power machines. Nonetheless, the efficiency improvements we see in Europe mean that larger outputs can be achieved with relatively less inputs, and therefore also with relatively less emissions. If underdeveloped and developing regions catch up with the developed world, it is important they do so with as little as possible detrimental effects on the environment. Efficiency improvements should therefore be supported also in these regions.

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[15] Note that Kander et al. and Csereklyei et al. used total energy consumption and total capital stock; due to data limitations we we compelled to restrict our analysis to modern energy consumption and capital stock in machinery and equipment.

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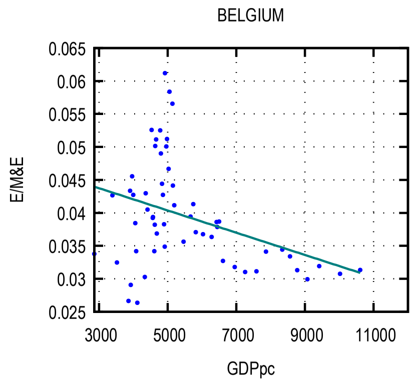
6 Additional Figures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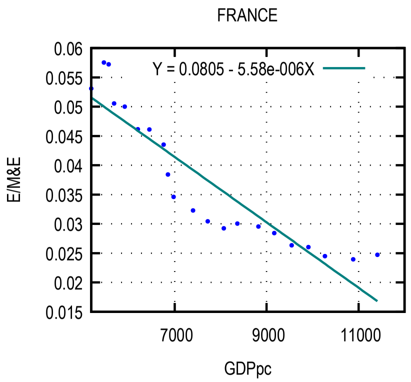
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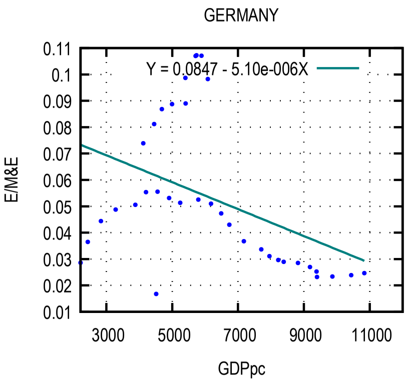
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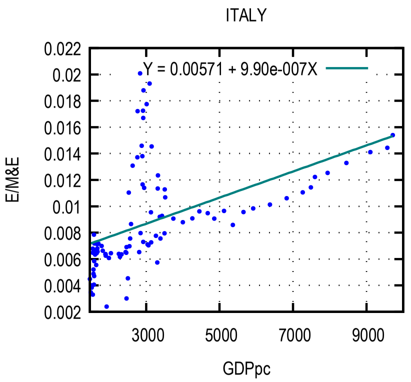
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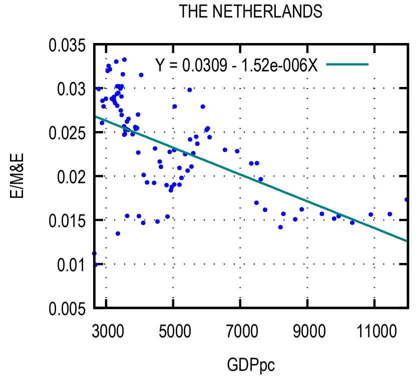
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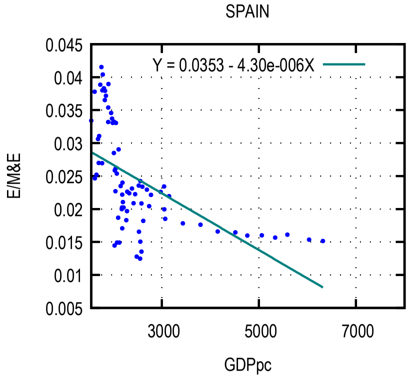
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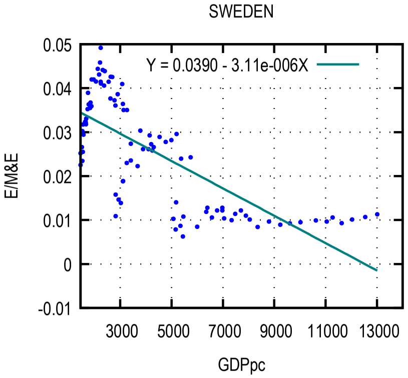
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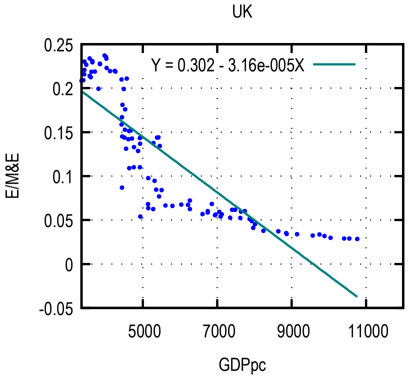
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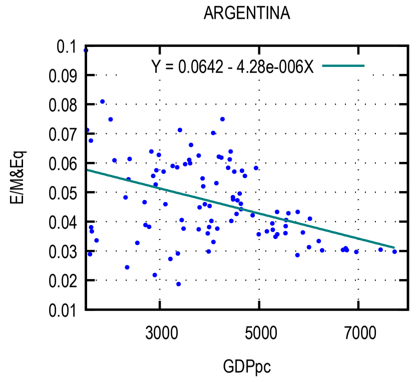
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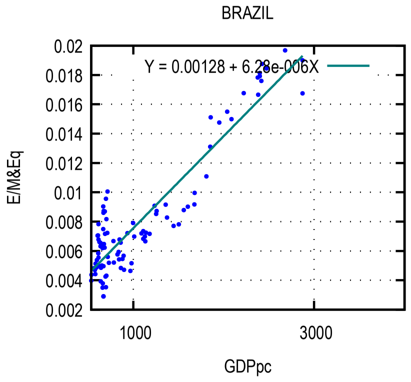
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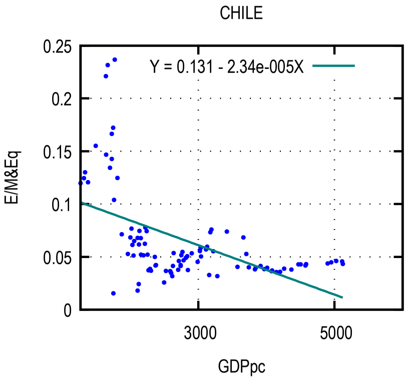
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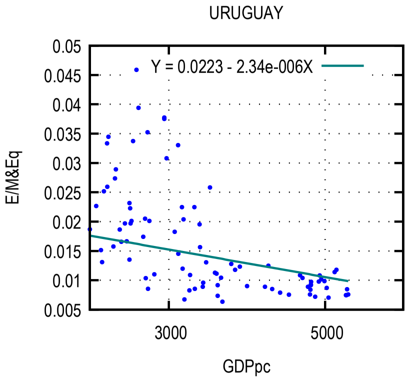
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