LUND UNIVERSITY
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Enabling Economic Growth

Energy Utilization and the Engines of Economic Growth

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Abstract

In this thesis I argue that the absence of energy utilization as a component in contemporary economic history and economic growth theory severely limits our understanding of economic development as a process. Although energy is not sufficient to explain the unprecedented expansion in the world economy since the industrial revolution, it is however absolutely necessary.

Technological progress remains the direct cause of economic growth in the long run, but innovativeness must be facilitated by economically beneficial institutions. There is a broad consensus about institutions as the engine behind long term growth. My intention is not to challenge that notion, but I want to stress that pinpointing those exact benign institutions has proven to be very difficult.

And even when we accept institutions as central to economic growth, one question remains: What has caused the differences in institutional outcomes across the globe? It has been widely suggested that competition is the key to institutional development, but I will argue that a purely quantitative outlook on competition does not explain institutional outcomes. Instead I suggest a more qualitative approach in the concept of contextual dynamism.

Key words: Economic growth, energy, institutions, contextual dynamism

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1 Introduction

Energy is vital, but often overlooked, as a component in to economic growth. Although the direct cause of economic growth is productivity enhancing innovations, these must in turn be facilitated by benign institutional arrangements. Energy however plays a central role in the economy. It can be utilized in an enormous variety of ways; nutrition, heating and to produce a vast array of goods. In this thesis I hope to specify the relationship between economic development and energy utilization. I also wish to contribute to contemporary institutional theory by discussing the causes of differences in institutional arrangements.

We humans spent most of our existence as nomads. Twelve millennia ago humans started to cultivate the land, prompting a slow but steady expansion of population and production. Muscle power of man and beast, but also wind and water power, provided the energy inputs into production.

During the last two centuries, as fossil energy resources were introduced in the world economy, both population and production have virtually exploded. World population has increased six-fold since 1820, income per head nearly ten-fold, and consequently world production grew sixty-fold (Maddison 2007, p. 69). However, this wealth has been very unevenly distributed among the world's inhabitants.

Modern economic history and growth theory stress the importance of institutions for economic development. The economy expands with technological progress. But this progress, in turn, has to be facilitated by institutions beneficial for innovativeness. Despite this, surprisingly little has been said about the causes of differences in institutional settings. This gap needs to be filled if we are to fully understand long term economic development.

This thesis is part of a larger, personal and ongoing, project called *Genesis of Economy*. It results from a frustration with an inadequacy of contemporary economic history and modern economic growth theory to explain what caused and enabled the industrial revolution and the subsequent exponential growth.

1.1 Questions and Results

It is widely accepted that the unprecedented growth following the industrial revolution is somehow linked to the discovery of fossil energy resources. Similarly, as we shall see, there is a strong connection between energy consumption and income levels among contemporary nations. However, ascribing any direct causality to energy utilization is not supported by empirics. But if this is not the case, the question asked must be: What is the exact relationship between energy utilization and economic growth?

Much has been written on the topic, but a coherent hypothesis regarding this relationship has not yet been formulated. In my view this limits our understanding of industrialization and economic growth as a process.

In Chapter 2, I aim to specify the relationship between utilization of energy resources and economic growth. I found that utilization of a new set of energy resources, i.e. fossil fuels, is not sufficient to explain the industrial revolution or the following demographic and economic growth. However, it is absolutely necessary. Furthermore, I argue that it is not energy utilization per se, but our ability to utilize that energy that causes growth. But this hypothesis just prompts the question: What determines our ability to utilize energy resources?

The "ability to utilize that energy" is merely a reformulation, though I will argue; an important one, of technological progress as a concept. And hence, many answers have already been suggested within the contemporary fields of economic growth and economic history.

In Chapter 3, I present and scrutinize suggested answers by the geographic schools and the institutional ditto. There is a consensus that the technological progress which drives growth has to be facilitated by progressive institutions. But exactly what institutions that have been most important for facilitating innovativeness and growth, is more widely debated. There is some consensus around the importance of property rights and free market, but I will show that even these arguments can not be accepted without complications.

One major question that goes unanswered within economic history is: If different institutions ultimately cause different growth paths, what then causes different institutional settings? Why did Western Europe foster the institutions that led her to industrialization, while others did not? A wide array of authors has, specifically or implicitly, identified competing nation states and competition as the determinant of economically benign institutional settings. But I will argue that this purely quantitative approach to competition is insufficient as explanation and needs to be complemented by a more qualitative approach.

In Chapter 4, I examine the competition argument and give it a qualitative dimension through the concept of contextual dynamism. I find the notion of a competing and competitive Western Europe against a non-competing and uncompetitive surrounding world to be flawed and insufficient. Instead the nature of the specific competition facing each region determines the specific set of institutions. I call this approach to competition contextual dynamism.

1.2 Theory and Previous Studies

This thesis aims to complement existing theories. More specifically, I hope to complement modern growth theory with a new outlook on the importance of energy utilization. Furthermore I wish to continue the debate within the field of economic history about the role of institutions and competition. Consequently the thesis has to rest solidly on work from both these fields. And any hypothesis rendered here, must also be scrutinized and subjected to counter arguments.

The causes of economic growth and prosperity have interested people since antiquity, at least. Intellectuals of that time stressed that the virtue of the right religion or ethnicity, i.e. their own, would determine material outcomes (e.g. Landes 1998). In Europe these thoughts dominated throughout the Middle Ages.

The early mercantilists of the 16th century stressed importance of bullion accumulation through controlled trade. The later mercantilists put more emphasis on the stimulation and protection of employment and production within high value sectors (Magnusson 1999). This would secure national wealth and power.

By contrast Adam Smith, in his *Inquiry into the Wealth of Nations*, argued that free trade and the consequent specialization would create benefits for all nations involved (Mokyr 1990, p. 5). David Ricardo followed with his theory on comparative advantages, which had similar implications. Trade and specialization however facilitates only one form of economic growth. Later generations would focus more on investment and technology driven development.

Modern economic growth theory can be said to originate from the publication of the seminal paper *A Contribution to the Theory of Economic Growth* by Robert Solow (Jones 2002, p. 20). The Solow model demonstrates how capital is accumulated through investment. Countries with high investment rates tend to have higher income, but capital accumulation can not alone explain long term economic growth (ibid., p. 33-36). Due to this fact Solow introduced technology, exogenous in his model, as the determinant of long term growth (ibid., p. 36-39).

No major attempt was made to define technological progress within an economic model until Paul Romer and Robert Lucas incorporated findings on how imperfect competition affects the incentive structure from the field of microeconomics (ibid., p. 2). Romer, in his endogenous growth model identifies the importance of research and development conducted by profit seeking actors in the economy (ibid., p. 96-97).

These thoughts also resound within economic history. For instance, Joel Mokyr (1990), in his *Levers of Riches*, highlights the importance of innovations. But it is not the innovations that are at the heart of his argumentation though, but innovativeness. He sees creativity and the incentives for it, as the driving force behind the industrialization in Western Europe in the 18th and 19th century.

This institutional approach to growth was fathered by Douglass North. He sees the rise of property rights as crucial to the European development, as it created incentives for investment and innovation (e.g. North & Thomas 1973). He also sees a competitive market economy as something uniquely European and that this competition was the main cause of its innovativeness (North 1993). It is also widely accepted within growth theory that institutional arrangements are central to any country's economic performance (Jones 2002, p. 143).

What about the role of energy in modern growth theory? Energy is almost totally neglected as a growth component. Energy resources are only included as a subtraction on the growth rate, as finite resources becomes increasingly scarce (ibid., p. 173-175). I agree with Shahid Alam (2009) that this does not capture the role of energy in the world economy, nor by any mean the environmental costs of their use. And this severely limits our understanding of industrialization and economic growth.

What has been written about the relationship between economic development and energy within economic history? Vaclav Smil's (1994) *Energy in World History* is perhaps the most comprehensive piece of literature on this subject. It is descriptive in nature, and although the work highlights the link between energy and economic development, he refutes any claims of causality, instead ascribing innovations and institutions as the true engines of growth.

1.3 Methods and Delimitations

Methodologically my thesis has little in common with the works of economic growth theorists like Solow and Romer, who use advanced algebra to formulate coherent growth models. Neither do I, within the scope of this thesis at least, make use of growth accounting, as does Nicholas Crafts (2004) in his evaluation of the role of steam in 19th century Britain. Methodologically this thesis draws more inspiration from Vaclav Smil (1994) or Kenneth Pomeranz (2000), who uses sets of data to support their argumentation.

I have also drawn on the combined effort of Douglas Hibbs, Ola Olsson and Jared Diamond (2004), who uses econometric analysis to argue for the importance of bio-geographical endowments to the differences in contemporary levels of national income.

I incorporate economic growth theory in this thesis, not so much as a method of analysis, but as a conceptual rally point, to which I connect lines of thought. This thesis also has minor influxes of trade theory and micro analysis. For instance, I make use of findings on the connection between imperfect competition and research and development from microeconomics.

The main method of analysis is to support my argumentation with data, presented in tables throughout the thesis. In regards to econometrics I have used the ordinary least squares method to support claims of correlation between variables of interest. As a guide to econometric analysis I have used the introductory book *Essentials of Econometrics* by Damodar Gujarati (2005).

In order to shed light on the relationship between economic development and energy consumption the following econometric model was specified:

$$lngni = c(1) + c(2) * lnenergy$$

Here lngni represents the logarithm of Gross National Income per capita and lnenergy the logarithm of energy consumption in kg of oil equivalent per capita, both sets of data retrieved from the World Bank web page (www.worldbank.org). Because of the exponential nature of both income development and energy consumption over time I have estimated the logarithm of these variables.

In Chapters 3 and 4 of the thesis I use a methodology more akin to social sciences, e.g. economic history. Still I draw support from empirics, but less so on economic statistics, due to lack of data on the topics discussed.

When studying world economic development one can only hope to include a small fraction of the subject at hand. There is nothing regrettable about that, since a complete narrative would have been both impossible to produce and read.

But two of these delimitations may make the explanations given here a bit simplistic, namely; class and gender. Changing class structures can impact institutional arrangements and thereby the economic growth process. And women's participation in the labour market has had an immense effect on modern economic growth, development and social life. Environment is part of the thesis, but is treated only *ad hoc*. This is regrettable as our environment is central to the possibilities of sustained growth, but was necessitated by the limited time frame.

1.4 Material and Data

I have relied heavily on secondary sources, literature consisting of books and articles from the fields of economic growth theory and economic history. In order to form a comprehensive view of modern economic growth theory I have turned to Charles Jones (2002). For a critical examination of the role of institutions I have been aided by Dani Rodrik (2003). And as growth theory is intertwined with the field of economic history, I have made use of work from leading authors within that field, e.g. Jared Diamond (1997), Joel Mokyr (1990), Douglass North (1973), David Landes (1998), Kenneth Pomeranz (2000), in order to capture the contemporary debate. Some of my data also comes from these secondary sources, but most come from more specific sources of macro data.

For historical data on levels and growth of GDP per capita and population, I have relied on Angus Maddison (2001). Though many of his findings deserve to be scrutinized, my time frame did not allow such an enterprise. But some of my critique can be seen in Section 3.2. and Appendix 2.

Data collection has been exclusively quantitative. GDP per capita data was collected from the *Penn World Tables*, 6.2 (pwt.econ.upenn.edu). Statistics on GNI per capita, in current international $, and energy consumption from 2006 was retrieved from the World Bank web page (www.worldbank.org). This was complemented by data on urbanization, also from the latter source, and GDP per capita from the *CIA World Fact Book* (www.cia.gov). I have also used data on the composition on energy consumption for individual countries from publications by the *Energy Information Administration* (www.eia.doe.gov). All data included in the model specified in Section 1.3 has then been processed through E-views.

2 Energy and Economic Growth

In this chapter I seek to specify the exact relationship between energy utilization and economic development. First, in section 2.1, I briefly outline the role of energy in the pre-industrial era. Here added energy, almost exclusively in the form of agricultural output, with time translated into an increase in population and only modest gains in living standard. This phenomenon was first formulated by Thomas Malthus, but also ceased to be true with the industrial revolution.

In section 2.2, I discuss the relationship between energy utilization, i.e. fossil fuels and the industrial revolution, together with the economic and demographic expansion that followed. Here I suggest that fossil fuel was necessary, but not sufficient for industrial growth. Yet, it is this necessity that highlights both its importance in the past as well as the contemporary challenges we face with regarding sustainable development and environmental degradation.

Finally, in section 2.3, I link my findings to the contemporary debate within the fields of growth theory and economic history concerning the importance of innovations and institutions as the engines of growth. I do this by a redefinition of technological development, arguing that there are merits to doing so, as it helps us to add a qualitative dimension to technological innovation.

2.1 Energy in History

Energy can take many forms; be transformed, and wasted, but never destroyed. Humans started separating from other apes about seven million years ago, but energy utilization did not differ much between them. During most of these seven million years early humans lived as hunters and gatherers. Nutrition, the consumption, gave energy that was spent on the acquisition, the production, of the very same. Nutritional intake equalled energy consumption up until about 250,000 years ago, when fire was first domesticated (Smil 1994, p. 17). These early humans had the intelligence to successfully make tools and fend of predators, then spread across the globe. Their spread was slow, but accelerating, and by 10,000 BCE all the world's continents were inhabited (Diamond 1997, p. 37-39).

The sustainability of this lifestyle varied across time and space. Largely sustaining, or forced to sustain, a delicate balance with nature these early humans however left an enormous ecological footprint in the Americas. When first appearing there their hunting skills were considerable, but the large mammals were totally unaware of the danger. As an effect, the so called Clovis culture wiped out the entire mega fauna of the twin continents. This would have an immense adverse effect on the biological, ecologic and thereby and economic conditions of later Native American cultures. (ibid., p. 49-51, 212-214)

Why did humans eventually start cultivating? Especially considering that energy returns per working hour was probably lower, at least initially? The most reasonable explanation is that the population expansion and climate change had brought about diminishing returns to hunting and foraging (Smil 1994, p. 22-24). Also cultivation was a far more secure source of nutrition. Even if it demanded longer working hours, it supplied some measure of rudimentary food security.

Domestication of flora and fauna created a whole new energy system. Grains provided a stabile source of nutrition with high energy content. Domesticated animals not only provided meat and dairy products, but some also provided kinetic energy to the agricultural production (ibid., p. 40-49). Horses, oxen and mules in most of Eurasia, water buffalo in East Asia, all aided their masters in production and transportation; horses even became decisive in warfare.

Population growth was rapid compared to hunting and gathering societies, but slow compared to modern. Economic growth in the agricultural societies was slow and uneven through time. The upward trend was modest, see Section 2.2, largely due to the fact that the creation and diffusion of innovations were relatively slow.

This is not to say that the innovations were not impressive. New or improved farming tools increased the yield from the muscle power of man and beast; like scythes, ploughs and harnesses (Mokyr 1990). Another form of innovation was the introduction of new crops. Like the crop exchange between the New and Old World, such as potato to Europe and wheat to the Americas, but also the high yielding Champa rice introduced in China during the Song dynasty. Animal husbandry, breeding stronger horses and oxen, was also to become an important mean of improving yields, particularly in Western Europe (Smil 1994).

Yet other agricultural innovations were organizational in nature. European agricultural output grew significantly due to the enclosure movement in the 18th century. And let us not forget the acquisition of new land, either by clearing forests, draining marshlands or conquering it from the sea, processes important in every densely populated region. Another important set of improvements available to agricultural societies was to intensify irrigation and fertilization, methods most developed in East Asia, i.e. China and Japan (Maddison 1998, Pomeranz 2000).

Then what about non-animal kinetic energy in pre-industrial manufacturing? Water and wind was harnessed with the introduction of mills, first used to process grain, but later also in textile and iron production. These mills were most common in Western Europe, particularly water mills in England (Mokyr 1990, p. 34-35). Water mills would continue to be important in Western European production even throughout the industrial revolution (ibid., p. 90-91).

Even though this thesis implies that thermal energy from fossil fuels became pivotal with the industrial revolution, it is still of interest to know: What effect did fossil fuel consumption have on the performance on pre-industrial economies? The answer does not come easy. When used as domestic heating, always as a minor source, any assessments are difficult to make. When used in metallurgy, glass and porcelain industry, one could imagine a cost-benefit analysis, but this would only produce sector wide results not national.

However we are not left entirely empty handed, for instance Jan Luiten van Zanden (1993) has asked whether or not the Golden Age in the Netherlands can be explained by the use of peat. He finds that energy consumption co-varies with GDP, but does not find any such connection to energy intensity. If the relative price of peat had fallen during this era it would stimulate energy intense production and thereby contribute to growth. But the price of peat relative to other goods actually climbed during the entire period (ibid., p. 275-276). van Zanden does however find that the low relative price of coal contributed the rise of energy intense production and thereby to the industrialization of the Netherlands (ibid., p. 276-277). A demand driven analysis might have yielded different results concerning the Golden Age. It may be that relative prices were pushed upward due to high demand during the 17th century?

But this is unsupported speculation on my part and of no major concern to this thesis. More so are van Zanden's findings on falling relative prices on coal and its contribution to industrialization, a more straightforward supply driven process, not very different from any other European nation at that time. His main point is that energy intensity does not explain variations in pre-industrial economy; neither would we expect it to. Studies of other nations would probably yield the same results. Keep in mind however that the cited study focuses on energy intensity, not energy utilization, and its links to economic growth. And van Zanden does show that in the long run energy consumption co-varied with production.

From the study of pre-industrial societies we can also conclude that although energy consumption to a certain extent co-varies with economic development. Shifts in energy systems did not bring about a new growth trajectory. And neither did the mere use of fossil energy resources. The English used coal in glass making, brewing and metallurgy in the 16th century (Landes 1998, p. 227). The Chinese used coal in steel making during the Song and natural gas in salt extraction (Smil 1994, p. 159, 167). The fact remains that in pre-industrial times all innovations, energy or non-energy based, had a limited effect on long term living standards. Technological improvement that increased output translated, almost exclusively, into population growth. According to the logic of Malthus this would eventually lead to diminishing returns, but the industrial revolution brought with it both unprecedented population and economic growth.

2.2 Energy Enables

In this section I show that the introduction of fossil fuels was necessary for the unprecedented economic, and to a certain extent demographic, growth in world economy ever since the industrial revolution in the 19th century.

In 2.2.1, I demonstrate that fossil fuels did not impact the population expansion during pre-industrial times or during the industrial revolution. But the unprecedented expansion during the last century would have been hard to imagine without fossil fuels. In 2.2.2, I argue that the relationship between energy and economic growth is that the former enables the latter, and that it is only because of fossil fuels that industrialization was made possible. Finally I summarize my findings in 2.2.3 and comment on the implications.

2.2.1 Population growth

Historically population expansion has increased along with the steady improvements in the agricultural sector. However both innovation and diffusion of best practice was fairly slow, as we have seen in section 2.1, at least prior to the 18th century (Smil 1994). Population growth faced some major interruption, like the 13th and 14th centuries when Asia and Europe faced the onslaught of the bubonic plague, and the 16th century Americas when its native population was brought to near extinction by smallpox and colonial rule (Diamond 1997, p. 197-199). Nonetheless world population grew along a steadily upward trend, from 268 million in 1000 CE to 603 million by 1700 CE (Maddison 2001, Table B-10, p. 241). This was due to innovations in agriculture such as; improved equipment, incorporation of foreign crops, creating farmland by draining marshland, fending of the sea, or improving existing farmland by increased irrigation and fertilization. Every such improvement left room for ever denser populations.

Table 1: Population in Chosen Regions and World Total (000)

Region/Year	**1500**	**1700**	**1820**	**1913**	**1998**
China	103,000	138,000	381,000	437,140	1,242,000
India	110,000	165,000	209,000	303,700	975,000
Japan	15,400	27,000	31,000	51,672	126,469
W. Europe	57,268	81,460	132,888	261,007	388,399
UK	3,942	8,565	21,226	45,649	59,237
USA	2,000	1,000	9,981	40,241	270,561
World	**437,818**	**603,410**	**1,041,092**	**1,1791,020**	**5,907,680**

Source: Maddison 2001, Appendix B, p. 241, Table B-10

All these innovations helped humans get more energy out of the same amount of land or, put differently, more out of the photosynthesis. Yet, we should not jump to any overtly deterministic conclusion. For instance, it is difficult to ascribe the population expansion in the 18th century to a shift in energy extracting technology. Any good historian would tell that the population expansion began, although at a more modest pace, long before the start of the fossil fuel era. The population expansion during the industrial revolution is better explained by innovations and institutional improvements rather than fossil energy inputs.

Today there is no direct connection between population size and energy consumption per capita. Why should there be? Population expansion is not dependent on overall energy consumption, but rather linked to a single form of energy, i.e. nutrition. By the logic of Malthus any increase in output, agricultural output, eventually leads to an increase in population, leaving little or no room for growth in income per capita. But as we shall see in the following section this process was broken in the 19th century, as both population and income exploded.

From 1700 to 1820 Europe experienced a rapid expansion of population, see Table 1. This process, by some called the agricultural revolution, has been widely studied by scholars and seen as a prelude to the industrial revolution. This would support Ester Boserup's claims; that population expansion can trigger innovation by pure necessity. This expansion has been largely attributed to the enclosure movement (Schön 2000, p. 43-44), and further output increase to diffusion of New World crops, especially potatoes, in the 19th century (ibid., p. 71).

And right before the industrial revolution there actually were some major improvements in agriculture; the enclosure movement, abolishing the commons, reserved land for pasture, drainage of wetlands, widespread use of mineral fertilizers and improvements in traditional equipment. New fertilizers came from collected guano or a chemical variety from mineral phosphates (Mokyr 1990, p. 120-121). Major improvements from the mid-19th century in medicine and hygiene have also been stressed as causing falling mortality rates. But some have noted that falling death rates began before the economic and medical innovations could have paid off, instead citing a decrease in the virulence among parasites (ibid., p. 54-55). These innovations and institutional improvements were specific to Europe, but not necessary for massive population growth.

Note that Europe was not alone in this population expansion. During the period 1700-1820, mostly under the reign of the Qianlong emperor, 1735-1796, (Smil 1994, p. 63), Chinese population grew dramatically, even more rapid than the European, see Table 1. It was even more dramatic still when looking at the official censuses, which leading researchers in the field have for some reason ignored (Deng 2003). This expansion however had no direct connection to any major shift in energy utilization (Smil 1994, p. 253). There was no rapid increase in fossil fuels and the New World crops had been introduced in China during the Ming dynasty. But then, why do we not see an expansion during the Ming?

My own thought on the Qianlong-expansion goes in two directions. The corruption and civil unrest of the late Ming may have led to miscalculations by officials and reluctance to perform adequate censuses. Or if the censuses are correct; the expansion can partly be explained by the lag created by the mismanagement of infrastructure, so vital to the agricultural performance. The subsequent civil wars and Manchu invasion also played their part. The rapid expansion during the Manchu would then also be an effect of a lagging performance. Only with the Qing consolidation did the New World crops fulfil their potential, as Kent Deng notes (2003, p. 62). Another important feature is the territorial expansion that opened new lands and alleviated the crowded Chinese heartlands (ibid., p. 59-60). The Chinese experience also teaches us something else; that population expansion does not automatically lead to economic growth.

The most astonishing population growth of the 19th century was experienced in the Americas. This was almost entirely due to the settlement, or resettlement, of the continents, especially the US. The migration was modest in the 18th century, but accelerated and climaxed during the 19th century (Cameron & Neal 2003, p. 287). This can be explained by the enormous environmental slack and opportunities for profitable cultivation that was offered by the vast and fertile expanses of North America, and to a lesser extent the pampas of South America.

With the introduction of fossil fuels in the in 20th century agriculture, a whole new production possibility frontier was introduced. New inorganic fertilizers and agricultural machinery would increase yields per acre further than any one could have imagined just fifty years earlier. Fossil fuels, first by components in fertilizers and later by fuelling machines, became a substitute for labour. In 1850, 60 per cent of the American work force was involved in agriculture, in 1975 that share had dropped to 2 per cent. Today synthetic nitrogen supply half of the nutrients used and half of the five-fold expansion in irrigation is due to diesel or electric pumps. (Smil 1994, p. 189-190)

Current energy inputs in agriculture are enormous and almost entirely supplied by fossil fuels. The U.S. production of one kilogram of nitrogen fertilizer requires 1.4 to 1.8 litres, amounting to a total of 15.3 billion litres, of diesel in energy equivalent. Moreover we also have to take into account diesel for machinery, transports, irrigation, packing and refrigeration in the entire retail chain. All in all each American consumes over 1.500 litres of oil equivalent (Pfeiffer 2003). However the U.S. is not unique; Chinese energy inputs amount to three times as much (Smil1994, p. 190). The production possibilities enabled by fossil fuels have prompted a wasteful management, ten kcal are required to produce just one kcal of food, this even excluding energy in cooking (Pfeiffer 2003).

It is not only in industrialized nations that fossil fuels have had an impact on agricultural performance. The so called Green revolution started in Mexico, but it was in Asia that reaped the biggest benefits, this largely due to the high yielding rice and wheat varieties (Rosset 2000). The big difference between this new rice and pre-industrial improvements was that crops previously were found in nature and these grown in laboratories. Petrochemical fertilizers were also a central part of the Green revolution in Asia and diesel driven pumps enabled even more intense irrigation (Smil 1994 p. 190). From 1950 to 1984 world wide grain output has increased by 250 per cent and energy inputs by 50 to 100-fold (Pfeiffer 2003).

What would have happened without fossil fuels in agriculture? Well, we would still have potatoes and other New World crops, as well as the medical advancements made during the 19th century. And not all synthetic fertilizers were fossil fuel dependent. Other important fertilizers like guano, or minerals, would of course still be available to the British in the 18th century. And although the Green revolution was immensely dependent on fossil fuels, innovations like the new high-yielding rice would of course be feasible even without them.

Furthermore, agriculture was slow to mechanize, not until after the First World War did tractors come into wide use in the Western world, and the rest has only begun the mechanization process (Smil 1994, p. 189). So for most part of the 19th century output in agriculture was largely independent of fossil fuels. But for how long could such a development continue?

The world experienced falling mortality rates and increasing population during the 19th century. So it is highly likely that the pre-industrial societies might have experienced some continued population expansion, especially those with some environmental slack, i.e. the Americas and to a lesser extent Europe, India and

Africa. But this process could not have continued indefinitely. Were it not for the mechanization and new fuel inputs in the 20th century, agriculture would have run into diminishing returns. One exercise of thought: If we were to substitute all current tractors in the US for horses, 300 million hectares would be needed to feed the animals, twice the arable land (ibid., p. 246). According to another estimate; if fossil fuels were taken out of the picture it would take three weeks of work to cover one day of consumption (Pfeiffer 2003).

Eventually the ecological barriers would have prompted diminishing returns, and what Fernand Braudel (1979) called the biological *ancienne régime* would have continued to rule. Without fossil fuels Malthus would have been victorious.

Let us look at a society that did not make a shift in energy systems, China. Whether or not the Taiping rebellion was a result of population growth and falling per capita earnings or the falling legitimacy of the Manchu after the Opium war remains up for debate. But what can be said is that population expansion without any shift in energy supplies seems to have added significant stress to the Qing dynasty, which fell in 1912 due to internal and external pressure.

2.2.2 Economic growth

From the middle of the 19th century, and onward, per capita income in Western Europe and North America has grown exponentially, and others, particularly East Asian nations have later followed suit. This happened simultaneous with an exponential growth in energy consumption, the introduction and rapid growth in use of fossil fuels. In order to answer how economic and energy processes interacted, let us first take a look at the empirical evidence.

Table 2: GDP per Capita in Chosen Regions and World Total
(1990 international $)

Region/Year	**1500**	**1700**	**1820**	**1913**	**1998**
China	600	600	600	530	3117
India	550	550	533	533	1746
Japan	500	570	669	1387	20413
W. Europe	774	1024	1232	3473	17921
UK	714	1250	1707	4921	18714
USA	400	527	1257	5301	27331
World	**444**	**615**	**667**	**1510**	**5709**

Source: Maddison 2001, Appendix B, p. 264, Table B-21

Overall growth in the world economy was slow prior to the 19th century. The Netherlands had experienced some growth in the 17th century, due to their advances in trade rather than energy, growth that can be called Smithian in nature (Mokyr 1990, p. 5). Also Britain, as the first industrialized nation, seemed to have experienced some growth during the 18th century, see Table 2. But even on this pioneer island growth took off only from the mid- to late-19th century (Cameron & Neal 2003, p. 283).

This corresponds in time with the take-off of coal consumption (Crafts 2004, p. 342). Coal dominated the 19th century production and transportation and in the 20th century it was substituted by superior crude oil inputs. As a comparison; in 1850, biomass accounted for 80 per cent of all fuels, by 1970 that figure had dropped to 15 per cent (Alam 2009, p. 20). I will examine the role of coal in the British industrial experience in detail later. But before a historical analysis of causality, let us look at the contemporary world and how the two variables of energy and income correspond.

Looking at the contemporary world there is solid, although complex evidence, that energy use and economic prosperity correlates. Historical data on the world as an entity is scarce. But from 1980 the world has witnessed a steady increase in both Gross National Income, GNI, per capita and energy use in oil equivalent per head. Table 3 shows that an increase in energy consumption explains 85.6 per cent of growth in income, and vice versa for that matter, from 1980 to 2006.

Table 3: The World: Energy and Gross National Income

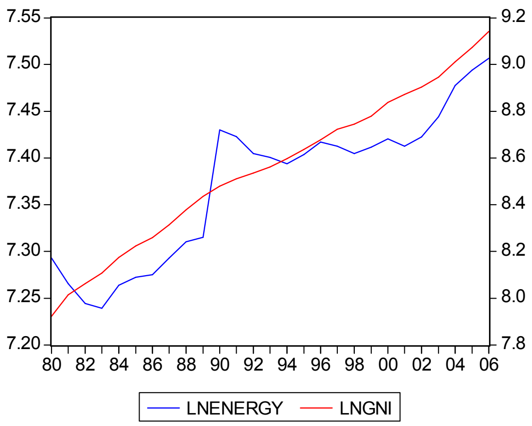
Method: Least Squares
Date: 07/23/09 Time: 16:08
Sample: 1980 2006
Included observations: 27
LNGNI=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-20.33588	2.361382	-8.611858	0.0000
C(2)	3.918517	0.320285	12.23445	0.0000

R-squared	0.856883	Mean dependent var	8.552677
Adjusted R-squared	0.851158	S.D. dependent var	0.339596
Durbin-Watson stat	0.619285		

Source: World Bank (www.worldbank.org)

Figure 1: Correlation: World Energy and GNI



The model, specified in Chapter 1, section 3, proves to be both economically and statistically significant. The same model has been used for the individual countries included, see Appendix 1. For the world however, it displays a problem with autocorrelation.

Autocorrelation implies that the model is still unbiased, but not the most efficient model (Gujarati 2005). As we can see the variables co-vary, although energy is more volatile. Furthermore we can see that the two expansions have not grown in the same pace.

While world GNI per capita has grown 238 per cent, from 2.762 in 1980 to 9.332 in 2006, energy consumption per capita has grown only 24 per cent from 1.470 to 1.820 during the same period. But this does not mean that energy has ceased to be important in the late 20th century, as I will demonstrate.

We must not confuse energy use with energy utilization. What the figures above, partly, illustrate is the increased energy efficiency in the world economy since the oil price shock of the 1970's. The energy efficiency has doubled in many advanced economies (Lomborg 2001, p. 125-126). The same efficiency trend can be seen in motor vehicles; from 13.6 to 22.5 miles per gallon between 1973 and 2007 (EIA 2008, Table 2.8, p. 59). Increasing efficiency is nothing unique to the late 20th century.

Table 4: Cross Country Comparison: Energy and Income

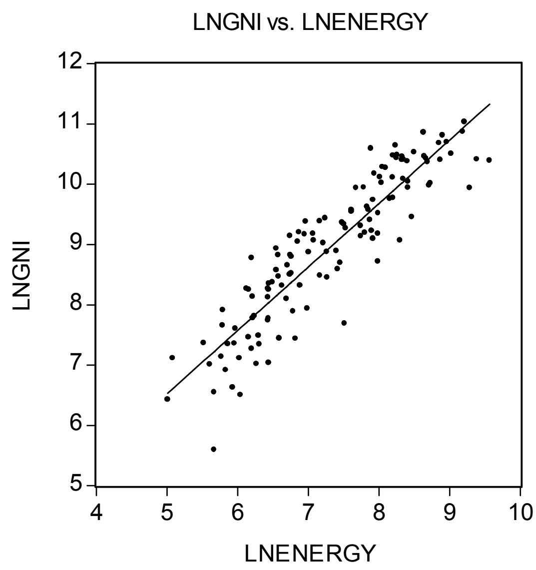
Method: Least Squares
Date: 07/23/09 Time: 15:56
Included observations: 127
LNGNI=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	1.258181	0.324917	3.872319	0.0002
C(2)	1.053000	0.044040	23.90989	0.0000

R-squared	0.820578	Mean dependent var	8.949092
Adjusted R-squared	0.819143	S.D. dependent var	1.215545
Durbin-Watson stat	2.119854		

Source: World Bank (www.worldbank.org)

Figure 2: Correlation: Energy and Income: Cross Country



From 1820 to 2003 the world economy expanded sixty-fold. The most prominent feature was the rapid expansion of machinery per capita, an increase of 155 in the U.K. and 372 in the U.S., at the same time energy consumption rose much more slowly (Maddison 2007, p. 73). This indicates rapidly increasing energy efficiency in machines (ibid., p. 73-74). This development is actually what characterizes every machine from the first steam engines to the latest hybrid car.

Nonetheless, the rapid increase in income relative to energy has sparked a decupling debate. The implications of this theory, its merits and limits, will be further discussed in section 2.3.

Another way of demonstrating the connection between energy and income is through a cross country comparison. Table 4 and Figure 2, above, show how high levels of energy consumption correlates with high gross national income levels and that correlation is very strong indeed.

There exists no poor country with high energy inputs, and no rich country with low energy inputs. The natural logarithm of energy explains 82 per cent of the natural logarithm of income levels. This compares favourably to 57 per cent of the logarithm of GDP explained by the geographic model by Douglas Hibbs and Ola Olsson (2004), and 67 per cent of the institutional quality model in the same study. Only their combined model, geography and institutions, comes close with 80 per cent of variation explained. (ibid., p. Table 3, p. 3719)

Another method to find an energy-income connection would be to study individual countries with different levels of income. The same energy-income-model applied to the world in Table 3 is here applied to individual countries. The results from these estimates are presented in Appendix 1. All presented results are statistically significant.

When it comes to economic significance, the strongest can be found in countries that have developed most rapidly during the period, Japan, South Korea, Malaysia and China, all with determination coefficients between 99.6 and 93.5 per cent. These results are the most important, as we would expect correlation to matter most during periods of economic expansion. It is weaker for the more mature economies, like the U.S., 53.1 per cent; were trends are diverging from the 1970's. For poor countries, like Nigeria with energy consumption having a negative impact, there is virtually no correlation, only 29.9. We would not expect it to be strong.

Furthermore, the U.S. and China, have slope coefficients of 2 and 3 respectively, this is an indication that energy efficiency in these two giant carbon dioxide emitters has increased over time, most likely due to the extent of past wastefulness. The slope coefficient for Japan is only 1. But slope coefficients should not be over-interpreted. Post-war Japan has always been extremely energy efficient and the on par increase is just an indicator that economy has expanded while high energy efficiency was maintained.

From the cross country analysis and the study of individual countries with different levels of income some conclusions can be drawn. First of all, no country has become rich without a significant increase in energy inputs. Secondly, energy plays different roles depending on were the country is on the income ladder. For rich countries, energy is important, but increasingly less so. For poor countries that have remained poor, energy is hardly significant at all. But those poor that have become or are becoming rich it is important beyond the point of vital.

So we can safely say that there is an indisputable correlation between higher income and increased energy consumption. But correlation does not necessarily imply causality, and the direction of causality can, and probably does, go in the reverse direction. Higher income levels cause increasing demand for electricity and energy intense consumer goods. I believe that would be the result of any year-to-year survey.

However causality is up for debate. Shahid Alam (2009) implies that there is some form of causality. In fact he views the economy in terms of energy flows and stress that it should be included in the neoclassical growth models (ibid., p. 2-3), even though he himself does not present any remodelling. In modern growth theory energy resources are only included as a deduction in growth rates as they become increasingly scarce. The consequence however is deemed to be modest (Jones 2002, p. 176-177, 189). Although I share Alam's concerns about the inadequacy of the current approach to energy, the reason for the thesis, I have to agree with the authors who oppose such statements of direct causality.

Smil, for instance, strongly opposes any claims of direct causality between energy use and economic growth. He exemplifies that while the Soviet Union put massive energy inputs into its economy, the richer Japan used less energy with far greater efficiency (Smil 1994, 252-253). Smil even goes as far as to state that; any energy centred narrative is fallacy. In his view, energy does not explain the major events in history, and energy inputs can only really guarantee pollution (ibid., p. 253-256), not income.

There is however a major logic problem with Smil's account. After stating that energy should not be the focus for economic development, he also states that we should learn to accept a low energy economy and thereby also a lower, or no, growth rate (ibid., p. 256). And while I agree with Smil, that energy in itself certainly does not explain major historical events, and while efficiency is naturally more important than the amount of input. The fact remains that neither Japan, as shown in Appendix 1, nor any other nation has managed an industrial transition without a massive increase in energy consumption.

Table 5: Electricity by Source, share (%) in brackets
(Billion Kilowatthours)

Country/ Source	**Thermal**	**Hydro.**	**Nuclear**	**Renew.**	**Total**
China	2 225.06 (81.88)	431.43 (15.88)	54.85 (2.02)	6.16 (0.23)	2 717.50 (100.00)
Japan	633.68 (61.36)	84.90 (8.22)	288.26 (27.91)	25.86 (2.50)	1 032.70 (100.00)
U.K.	280.38 (75.38)	4.56 (1.23)	71.68 (19.27)	15.34 (4.12)	371.95 (100.00)
Sweden	3.99 (2.88)	61.11 (44.10)	63.63 (45.93)	9.83 (7.09)	138.55 (100.00)
U.S.	2 884.39 (70.85)	289.25 (7.10)	787.22 (19.34)	110.40 (2.71)	4 071.26 (100.00)
World	**11 943.04 (66.30)**	**2 997.06 (16.64)**	**2 660,26 (14.77)**	**414,31 (2.30)**	**18 014,67 (100.00)**

Source: Based on EIA 2006: Recent Electricity Generation Based by Type. (www.eia.org)

Another way of looking at the importance of fossil fuels is by its share in current electricity consumption, see Table 5 above. Thermal energy from fossil fuels makes up a vast majority as the source of the worlds electricity, especially prominent in the world's largest economies; the U.S., China and Japan. Sweden together with Norway, not included, has a far higher share of hydroelectric power than most industrialized nations, but only because of natural endowments.

But electricity generation does not provide a complete picture, as it is at the cleanest end of our energy consumption. Internal combustion engines are used both in transportation and various forms of production, e.g. mining, irrigation pumps, etc. All in all; oil, gas, and coal provide a whopping 80 per cent of the world's energy needs (Lomborg 2001, Figure 71, p. 130).

Now that we have confirmed the centrality of energy inputs in the modern economy, let us now return to the industrial revolution. Let us ask whether energy utilization had a decisive role in the higher growth trajectory experienced from this point in history. This question is partly linked to the debate of how much of revolution the industrial revolution actually was?

As we have seen above economic growth has been exponential ever since the 19th century. But this does not automatically answer whether we should see growth as a linear process that took off, into a whole new trajectory, or as a continuous exponential process?

There are two schools of thought on the industrial process that started in 18th and 19th century Britain; continuity and take off? The first school sees it as a continuation, be it an acceleration, of a growth that started centuries before the so called revolution, and that it more a question of industrial evolution. And if the industrial revolution was a continuous exponential process that started much earlier, energy may not have been the crucial component.

The continuation or revisionist school, stressing gradual development, was led by Phyllis Deane and W. A. Cole. Knick Harley (1982) and Nicholas Crafts (1985) found that growth has not been as impressive as previously thought. This view is also accepted in the narrative of Rondo Cameron and Larry Neal (2003) stressing the gradual aspect of the industrial revolution, at least prior to the mid-19th century. While Joel Mokyr (1990) and David Landes (1998) both share the view that the industrial revolution was indeed a revolution.

Crafts (1985) stresses the slow growth in productivity and relatively slow economic growth during industrial revolution, 0.6 to 1.7 per cent, at least before 1830. This claim may actually strengthen any view about the importance of energy. As we shall see, steam power became a major source of British energy supplies only after 1830. But the importance of steam power has also been challenged by Crafts (2004). He sees a narrative of 19th century industrial development in Britain centred on steam as misleading. Let us examine that view.

Crafts argues that steam power did not contribute much to the total factor productivity or capital deepening of 19th century Britain and less than the ITC-sector has in our days. With growth accounting, Crafts claim that steam did not contribute much, even to the modest growth. But is not as devastating to an energy utilization hypothesis as it may seem?

First let us take a look on what Crafts does not say. Let us remember that steam power is not equal to coal energy. A dramatic increase in coal inputs in metallurgy drove steel prices down and quantity and quality up (Smil 1994, Mokyr 1990), making industrial inputs far less expensive.

And then what Crafts he does say. When it comes to Crafts conclusions he misses the point, total factor productivity and capital deepening do not capture the contribution of the new power source. From 1831 to 1870 only one-third of British growth came from total factor productivity, the remaining two-thirds came from capital and labour in roughly equal shares (Crafts 2004, Table 1, p. 339). Furthermore, most of the capital added was centred on steam technology, perhaps not in the initial phase of the industrial revolution, but inarguably later on. Some of the growing factor productivity came from structural advances, like the move out of agriculture in to industry. This also would have been impossible without the addition of capital stock, which owed much to cheaper inputs. Only the growth in the labour force, caused by improvements in agriculture, has no clear links to coal at this time. Also early 19th century food transport was fairly independent from steam technology, as canals were of higher importance than the railroad.

Looking at the sheer output of energy supplied by steam power, see Table 6 below, it is hard to imagine any other source could have provided the energy needed in the expanding production. And herein lays the problem with a sheer per capita growth assessment of the industrial revolution. The industrial revolution was not so much a question of higher labour productivity, as one of increased production. Population expanded almost on par with productivity (Mokyr 1990, p. 82), at least up until 1830. Later, between 1831 and 1873, British per capita growth picked up to 2.4 per cent (Crafts 2004, Table 1, p. 339). This corresponds in time with the shift towards coal powered steam technology.

Table 6: Sources of power in Britain, 1760-1907
(Horse power)

Source/Year	**1760**	**1800**	**1830**	**1870**	**1907**
Steam	5,000	35,000	165,000	2,060,000	9,659,000
Water	70,000	120,000	165,000	230,000	178,000
Wind	10,000	15,000	20,000	10,000	5,000
Total	**85,000**	**170,000**	**350,000**	**2,300,000**	**9,842,000**

Source: Crafts 2004, p. 342, Table 3

The question of take-off versus continuation can be linked to the question about divergence between Western Europe and/or Great Britain and the rest of the world. When did it begin and how dramatic was it? A short summary and selections from the debate is justified:

The notion of a significant economic advantage for Western Europe in pre-industrial times, which had reigned since Adam Smith, Karl Marx and Max Weber, was cemented by e.g. Douglass North. This view was challenged by Andre Gunder Frank (1998), in his *ReOrient*, stating that there was no major difference in living standards between Europe and the more developed parts of Asia prior to 1800. David Landes (1998) in his *The Wealth and Poverty of Nations* in turn refutes Gunder Frank's claims as pure nonsense. Kenneth Pomeranz (2000) in his *The Great Divergence* revives the argument, that there was little or no difference in living standards between Europe and China or Japan up until 1750.

Pomeranz may or may not be correct about his assumptions about Chinese economy, more about this in Chapter 3, but for now it is his main point that is of interest for the current purpose. Not seeing any major difference in standard of living, capital availability, innovations or institutional arrangements that could have caused an industrial breakthrough in any continent prior to 1750 he argues: That without the ecologic relief offered by the New World and coal inputs, England would have run into diminishing returns to capital and labour instead of an industrial revolution. The ecological situation at the time of the industrial revolution will serve as evidence.

During the 18th century all of the densely populated core regions of the world began to feel ecological stress (ibid., p. 211-212). The stress in England was becoming increasingly acute (ibid., p. 215-217), and had it not been alleviated with imports of cotton from the Americas, grain from Ireland (ibid., p. 217), sugar from the Caribbean and iron and timber from America, Scandinavia and the Baltic region, diminishing return would certainly already have been in place. The 25-30 million “ghost acres” added to Britain from the combined imports surpasses its own arable land with margins (ibid., p. 276). The rest of the world did not have the same kind of peripheries to draw land intense goods from, or export capital intense goods to. Moreover no other nation had coal as geographically available as England, close to its industrial core, in contrast to China (ibid., p. 61-64). Coal deposits gave England an equivalent of 15-21 million additional acres of forest per annum. Without these resources England would have run into diminishing returns, and probably forces down a labour intense growth path rather than an energy and capital intense one (ibid., p. 280-281). Such a development would have been aggravated as England’s traditional raw material supplying peripheries, like Northern Germany and the U.S., started catering to there own infant industries in the mid-19th century. Without the new energy inputs the industrial revolution could still have become an unprecedented pre-industrial boom, but diminishing returns would have disabled any overall higher growth trajectory.

At first it may appear that Pomeranz offers the answer to all my problems, but in fact, he highlights other necessary factors for economic development than just energy resources. He sees American cotton and other colonial commodities as vital to the industrial revolution in England, perhaps even more so than coal (ibid., p. 276). And there is no point in arguing about the importance of energy resources when other inputs were just as pivotal.

To counter this line of thought, I will have to look at industrial processes outside of England. Germany as an example became industrialized based on its steel and chemical industries (Cameron & Neal 2003, p. 306-308), neither cotton nor other colonial commodities were available in large volumes. The same can be said for most other continental European economies.

This reasoning opens up to an array of contra factual speculation: Could any continental European nation have industrialized without England in the lead? Well, many 18th century innovations did originate in England, but many also had their origin in other nations (Mokyr 1990, p. 240), like the vacuum conservation of food by Nicolas Appert or the soda making process of Nicolas LeBlanc, both Frenchmen. Other European nations were not in a technological backwater compared to Britain and industrialization on the continent may have been possible, but this remains speculations. Nonetheless the continental European nations show us that industrialization as a process is possible without cheap colonial goods. So while energy resources are not the only necessary inputs, they constitute the only common denominator that would enable not just the industrial revolution as we know it, but any feasible industrial process.

And this is also what happens. During the early industrial revolution, 1750-1830, we see that the technological improvements fail to render much economic growth. Only after 1830, when steam power makes its breakthrough was long term economic growth made possible. And even if water power improved drastically during the 18th century (ibid., p. 90-91), looking at the contemporary U.K. with over 75 per cent of its electricity generated by thermal energy it is hard to imagine any viable substitutes, see Table 5 on page 16.

In this sense the industrial revolution was an undisputable take-off. Not because there were no or even little innovations made previously, 17th century Holland and 18th century England achieved growth rates impressive at the time. But had it not been for the new energy resources made available, there would not have been any continuous exponential growth. Today, that growth has yielded unprecedented high living standards across the globe, although very unevenly distributed. In terms of "servants" given by additional energy, today each European has 150, each Indian 15, and American 300 (Lomborg 2001, p. 119).

What then is the relationship between energy and economic growth? Drawing on both the analysis of contemporary economies and past experience I feel confident in stating that: While energy is not a sufficient condition for industrial growth, it is however necessary. It is the *sine qua non* of long term economic growth. Without substantial energy inputs no nation can hope to achieve high overall incomes. Traditionally this has only been achieved through massive inputs of fossil fuels, with adverse consequences to environment and health. Such statements have immense moral implications and raises acute questions about responsibilities of those nations already rich and those aspiring to become so.

2.2.3 Consequences

Energy does neither cause economic nor population expansion, but enables them, it is the *sine qua non* of economic and population growth. Improved nutrition has historically led to population growth, eroding long term economic growth per capita, Malthus's dismal science. Only with the massive increase of energy input, due to the utilization of fossil fuels in production, have we experienced long term economic growth. In order to understand why this conclusion is important to reiterate, we must ask: What consequences does this have?

The growing strategic importance of the Middle East may highlight the importance of energy. Even so, I agree with Smil (1994, p. 251-256) that energy utilization does not explain the major events in history, e.g. the rise and fall of empires, the civil rights movement or female participation in the labour market.

However I would like to add: That even though energy can not explain most major event in world history, they are indispensible in explaining the single two most revolutionizing: The shift from hunting and gathering to agriculture and the shift from artisanal to industrial manufacturing.

In practice for economic theory; the emphasis on energy challenges the absolute emphasis on institutions and as the sole factor that enables of growth in the long run. Regardless of how well developed and functioning institutions we have, without energy – they will not materialize into economic growth.

The same goes for financial capital, at least in the early stages of the industrial revolution. One must remember that it was not lack of financial resources that made progress slow in the pre-industrial societies; rather it was a lack of investment opportunities (Braudel 1979, quoted in Pomeranz 2000, p. 179). Instead of investment in modern real capital, e.g. machinery and industrial infrastructure, financial resources were often channel towards luxury consumption, warfare, shipment, or agricultural infrastructure. The technology was just not in place yet and thereby nor was the ability to utilize the required energy for such investments.

But surely it is those innovations that are of importance, and not the energy? We have seen above that energy resources do not make any difference to growth without the right technology to utilize it (Mokyr 1990, p. 159-162). But the exact same logic can be reversed. Technology in itself does not create a whole new growth trajectory without the energy to power it. What is the point in having a brand new laptop, or any electric appliance, without the electricity to run it?

However, it is clear that energy utilization per se has not caused economic growth. But then we must also formulate what has. The answer of course is to be found in our capabilities, our technology, or as expressed in this thesis our ability to utilize energy. The merits with this formulation or reformulation of technology will be discussed in the following section.

2.3 Ability Determines

Energy is the *sine qua non* of industrialization. And, neither technology without energy nor energy without technology can fully explain the unprecedented demographic and economic growth since the industrial revolution. To reformulate; it is not energy utilization per se, but the ability to utilize energy that determines economic growth, or material prosperity to be more correct. Below I have formalized the relationship between energy utilization and material prosperity in a hypothesis.

Humanity's material prosperity is determined by our ability to utilize the energy in our surrounding environment.

Such an energy centred hypothesis is not without its problems. Let me here pick up the decupling debate that I so rudely dropped in the beginning of sub-

Section 2.2.1. In the U.S. energy has fallen both as factor share and in per capita terms since the oil price shock in 1973 (Jones 2002, p. 183-184). And Denmark has actually managed to increase its GDP per capita while decreasing its energy consumption (Lomborg 2001, p. 126).

One reason, as stated above is increasing energy efficiency, i.e. increased ability. But another factor is the ever higher and growing share of GDP coming from the less energy intense service sector. Not only has the service sector grown in terms of share of employment, especially in the public sector, but the service content of manufactured goods has also risen (Bryson, Daniels and Warf 2004). Much of the value addition to goods today stems from the drawing board, and not the assembly line. Design and branding determines more of the price than the energy required per unit.

But acknowledging that energy is becoming less and less important for income in the industrialized economies is not the same as saying that it will become an obsolete component in economic development. This development is actually quite hopeful if we believe in a sustainable future. But energy utilization will always continue to matter for the rich, even more so for the poor striving to become rich. Remember that the statistical analysis in sub-Section 2.2.2 and the data presented in Appendix 1 show that all nations that have become rich, or substantially richer, during the period are those where increased energy consumption seems to have mattered the most. But probably they will use less, and hopefully cleaner, energy as their economies develop, for all our sakes.

And when looking at the contemporary energy situation, our dependence on fossil fuels, and its implications for the economy and the sustainability of growth; we all inevitably have to make a transition to a sustainable growth path.

Now note that the expression; "our ability to utilize energy", is actually just a redefinition of technological improvement, but it implies that energy innovations holds some form of economic primacy. The combustion engine meant more for the world economy than the once so popular toy *Tamagotchi*. This can help explain why the increasing numbers of issued patent (Jones, p. 91-93) are not yielding higher growth rates in the industrialized economies.

This does not dispute the importance of technology for economic growth. Its central role is evident and has been formalized in economic growth theory by e.g. Robert Solow. In the Solow model technology is the ultimate determinant of growth (Jones 2002, p. 36-38). Although given exogenously; the growth rate of technology will determine the growth rate of any economy in the long run or, more accurately, in the so called steady state (ibid., p. 38-43). Technology is also the main growth component for all subsequent economic growth models.

But this does not conflict with the notion that some innovations are more important to economic growth than others. This is quite logical and has already been noted by many. And in Lennart Schön's accounts (2000); of the key innovations that drives structural cycles, a majority were within the fields of energy utilization or transmission.

Does this rethinking of economic growth have any policy implications? It could imply that I would recommend a shift in policy towards energy research.

Although research in renewable energy resources is vital for our future, breakthroughs can come from almost any direction. Take electricity, so central to improved energy utilization. When first discovered it was mostly used as a novelty for practical jokes and its primary applications thought to be within medicine as electro-chock therapy.

Viewing energy resources as exogenous has immense drawbacks as it limits our understanding of the industrial revolution and present day economic prosperity, but also in our ability to grasp interconnectedness between energy, labour and capital. Alam (2009, p. 4-6) contrasts this to land in the classic growth model, which did put a limit on growth.

Note that I do not, like Alam, see that energy absolutely has to be incorporated in the modern growth models. Even though its absence limits capabilities of explaining the shift in growth trajectories, modern growth theory still manages to explain growth in the modern industrialized world quite well. And I can not see, nor does Alam to my knowledge present, any method of incorporating energy into the modern growth models. Still energy should be seen as an indispensible part of explaining economic growth, and limits to the same.

For even if fossil energy resources will continue to be available in the near future, and peak oil may be far away, views I share with Lomborg (2001). I strongly disagree about his views on the harm caused on the environment, not just climate change, but also the general degradation of ground water supplies, sea and air. These concerns become even more acute if we believe that all human beings should have access to the prosperity that we in the West experience.

And even though our immediate concern should be environment rather than resource depletion (Smil 1994), the mere logic behind finite resources must convince us that their presence should not be taken for granted in the very long run. Civilization should not be built and sustained just centuries, but millennia.

Supported by the fact that fossil fuels have been indispensible for our current population size and income levels I have to disagree with Al Gore's logic: That we can not rely only on improved technology but must also conserve. Instead I would stress: We can not rely only on conservation, we must improve technology!

In other words we must continue to improve our ability to utilize energy. But, if our material prosperity is determined by this ability, the question that arises and should be tackled now is: What actually determines our ability to utilize energy?

3 The Ability to Utilize Energy

We have already seen that without fossil energy inputs innovations by themselves could not have caused the industrial growth trajectory. On the other hand, those energy resources have always been available for utilization by anyone with the right technology. Even if we can accept that our material prosperity depends on our ability to utilize energy and that economic growth is almost, but not entirely, linked to material prosperity, the question still remains: What has determined the differences in the ability to utilize energy resources?

Central to the debate about what was the root causes of the technological achievements brought on by the industrial revolution and the new trajectory of growth, is when the process actually started. This question is inevitably linked to that of when the divergence between Western Europe and the rest of the world began. In Section 3.1, I will examine this debate concerning divergence. In Section 3.2, I will examine how initial resource endowments have affected different levels of technology. Innovations themselves may have had an effect on innovativeness and institutions that facilitate innovativeness were crucial for long term development, these factors will be discussed in Section 3.3.

3.1 Different Abilities

For the purpose of understanding why some nations have reached high levels of technology and income while others have not, we must ask: How large was the technological and economic divergence and when did it start?

Let us recapitulate from Chapter 2 the debate surrounding global divergence in the pre-industrial world: The notion of a significant advantage for Western Europe goes back to Adam Smith, Karl Marx and Max Weber, and has in modern times been reiterated by Douglass North (e.g. North & Thomas 1973). But this view was challenged by Andre Gunder Frank (1998) who claimed that there was no major difference prior to the industrial revolution.

David Landes (1998) in his turn refutes Gunder Frank's claims and repeats the argument that Western Europe was well ahead of the rest of the world centuries before the industrial revolution. He stresses the superiority of West European institutions as well as its innovations. Landes's work is mostly a historical narrative relying on qualitative sources, with few quantifications or comparative data. It should absolutely not be disregarded on that basis, but it becomes hard for an economist to evaluate his argumentation.

Angus Maddison, on the other hand, is one of the foremost sources of quantitative historical data. His work of estimating past levels of population and

GDP per capita is unique in scope and scale, and because of this he has become the main source of historical economic data even in this thesis. He also sees a divergence between Western Europe and the rest of the world, between the 11th and the 16th century (Maddison 2007, p. 70-71). However his estimates should not be accepted without some scrutiny. For instance, he relies heavily on urbanization ratios (e.g. Maddison 2001); especially in his assessment of the China-Europe divide (Maddison 1998).

The urbanization ratio is a widely accepted measure with an enormous theoretical appeal. In pre-industrial societies we would expect large agricultural surplus and productivity in the countryside to push people into cities. Moreover commercialization and urbanization go hand in hand and could have had a pull-effect on industrious and adventurous individuals. Cities could offer a larger scope for specialization and thereby higher income.

When examining contemporary data we find an almost 53 per cent correlation between the logarithm of urbanization ratio and the logarithm of GDP per capita. Explaining more than half the variation, this would give support the theoretical assumptions above. But when looking at poor nations below the $2.000-line, below which we would find all pre-industrial nations, there is virtually no correlation, see Appendix 2. There is no denying that Europe had a growing share of its people living in cities, a share increasing with income. In China no similar development can be seen. But keep in mind that city-dwellers of the time were not necessarily better of than their rural contemporaries. Also Maddison's data on life expectancy is biased against East Asia as infanticide was a common family planning practice there (Pomeranz 2000, p. 38).

Table 7: Share of World GDP for Chosen Regions
(per cent of world total)

Region/Year	**1500**	**1700**	**1820**	**1913**	**1998**
China	25.0	22.3	32.9	8.9	11.5
India	24.5	24.4	16.0	7.6	5.0
Japan	3.1	4.1	3.0	2.6	7.7
W. Europe	17.9	22.5	23.6	33.5	20.6
U.K.	1.1	2.9	5.2	8.3	3.3
U.S.	0.3	0.1	1.8	19.1	21.9
World	**100**	**100**	**100**	**100**	**100**

Source: Maddison 2001, Appendix B, p. 263, Table B-20

Kenneth Pomeranz (2000) makes extensive use of data to support his claim that China and Japan, and to a lesser extent India, was on the same level of living standards as Western Europe prior to the industrial revolution. Pomeranz argues that China were not behind Europe in the 18th century. He estimates Chinese life expectancy to have been between 35 to 40 years, comparable to that of England (ibid., p. 36-38). And caloric intake is estimated to be similar or above that of Western Europe (ibid., p. 39). We must keep in mind that Chinese agriculture was much more productive, although far more labour intensive, than the European. It yielded on average about 2.5 tonnes per hectare during the 17th century (Smil

1994, p. 62-63), compared to 1.5 tonnes of wheat per hectare in 19th century Western Europe (ibid., Figure 3.15, p. 75).

Although nutrition, and especially grain (Parthasarathi 1998, p. 83), constituted a majority of pre-industrial consumption overall living standards are harder to quantify and compare. But the number of pieces of furniture in rural households (Pomeranz 2000, p. 144-146) and everyday luxury consumption per capita was roughly the same in China as in Western Europe (ibid., p. 117-127).

Historical economic research on India is harder to come by and data is sparser than on China and Japan. However we are not left completely in the dark. For instance, Prannad Parthasarthi (1998) assesses the performance of the South Indian pre-industrial economy. He explains that the low prices of Indian goods and cheap labour did not result from oppressively low wages, but low grain prices. This gave the South Indian farmers and weavers a purchasing power comparable or superior to English grain wages (ibid., p. 83-89). Does this imply similar living standard? It might, but in my own recent experience I have found that tropical climate also requires a higher caloric intake, so not necessarily.

The decline of India in the world economy began prior to the industrial revolution, both in relative and absolute terms, according to most estimates (e.g. Maddison 2001), India's share of the world economy declined from 24.4 to 16.0 per cent during the 18th century, see Table 7. David Clingsmith and Jeffrey Williamson (2005) ask what reasons there might have been for this "de-industrialization". They give a two-pronged explanation.

First the internal problems due to the fragmentation of the Mughal Empire from the early 18th century led to increased taxation and increased own-wages in the manufacturing sector. In turn this led to increasing prices of Indian manufactured goods. India lost much of its export market as a consequence (ibid., p. 20). And, during the 19th century India would loose much of its domestic market, mainly to the British. This was caused by the British industrialization and India's free trade commitment under colonial administration (ibid., p. 20-21). But the India was still a giant in the 18th century global economy.

The views of Pomeranz and Parthasarthi have been challenged by Steven Broadberry and Bishmupriya Gupta (2006), repeating the argument that Western Europe was striving ahead of the rest of the World long before the industrial revolution (ibid., p. 26-27). Although wages in terms of grain were fairly similar, they observe a large and growing difference in silver wages between Western Europe and Asia. However, their claim rest on the assumption that the silver wage gap is not a monetary phenomenon resulting from Western Europe having more silver flowing through their economy.

They argue that this was not the case, relying on the fact that the bimetallic ratio of gold and silver converged over time (ibid., p. 21-23). Silver was worth relatively more in India and China, than in Europe, due to the shipments of silver mined in Spanish America. This created an arbitrage situation for European merchants, paying relatively little silver in Asian ports and upon returning they received relatively large amounts of silver, above regular trade profits that is. This could continue until the massive inflows of silver made its price versus other goods converge between the regions. This has been measured by the gold-silver ratio, which converged in 1650, then diverged, to converge again in 1750 to 15 units of silver per unit of gold in both England and China (ibid., Table 11, p. 23).

However, if there was an arbitrage situation reflected in the gold-silver ratio there is also another possibility, direct arbitrage between gold and silver. Turning to the history books this is exactly what we find. The initial trade between China and the European trading companies were actually dominated by gold bullion from China and silver bullion in the reverse direction. This trade reached a peak in 1720-1750 (Wild 1999, p. 44). Such an explanation fits better in time than absolute trade volumes, which peaked decades later.

Furthermore, keep in mind that only one third of the European silver reached Asia (Maddison 2007, p. 91), where it was received by China and India, each economy as large as the European. And although these countries also experienced inflation it seems unlikely that the amount of silver received from trade would push real prices and wages to European levels. For these reasons I wish to refute the conclusions drawn by Broadberry and Gupta. If there was a great divergence prior to the industrial revolution it can not be shown by the silver wage gap.

Although one observation made by Broadberry and Gupta should be taken more seriously. During the 18^{th} and 19^{th} century grain wages fell, first in India (ibid., Table 6, p. 17) and then in China (ibid., Table 9, p. 19), both relative to the U.K. and in absolute terms. This indicates that the two Asian giants had begun to run into diminishing returns.

But there is still some substantial evidence that the divergence prior to the industrial revolution was not as wide as previously thought. Does such a conclusion have any major consequences? Well, limited divergence before the industrial revolution reiterates its centrality for the continuation of Western economic dominance, and above all their ability to pull further ahead of the pack. But in other respect it would not have mattered. Europe was militarily dominant long before it became economically dominant. And nothing could have stopped the decline of the Mughal and the Manchu dynasties, which succumbed as much to internal as external pressure.

After this long journey we are not much wiser. The conclusions drawn here are just one addition to a debate that has raged, and will continue to rage, among economic historians. The fact remains that Western Europe still was the first that acquired the ability to utilize fossil fuels in large scale production, followed, and later surpassed by the U.S. Let us now move ahead to the major suggested explanations of long term technologic development and economic growth.

3.2 Endowments

If we are dependent on the ability to utilize energy in our surrounding environment, perhaps the explanation to technological development lay in the environment itself? How has the endowment of natural resources, climate, biology and minerals, helped facilitate innovations?

An entire school of thought circles around this line. In the early 20th century Ellsworth Huntington of Yale attempted to explain the interplay between humans and their surrounding environment. But attributing almost every aspect of human history to geography, he and his followers went too far. After World War II geography, which had unfairly been caught in the draught of smelly racial ideology, was shunned by the intelligentsia (Landes 1998, p. 27). But in one sense geography is perhaps the least "racist" of all possible explanations, as it has the odd ability to condemn a nation to poverty, without blaming anyone. It is not your fault for being born in the "wrong" country.

The logic appeal of geography is obvious. Without the existence of energy resources it would be impossible to utilize them. And, if the energy utilization is the *sine qua non* of economic growth, then resource endowment is the *sine qua non* of energy utilization. Furthermore, geography as opposed to both energy utilization and institutions has no issues with direction of causality. Both higher energy consumption and good institutions could be the effects of higher income, whereas beneficial climate can not.

And the fact remains that the richest contemporary economies are found in the temperate zones (ibid., p. 29). Deserts are barren by nature and lack of water prohibits large populations. Tropical zones, containing a vast majority of the world's species, seem to disfavour humans with disease carrying parasites, heat and humidity. But climate alone does not guarantee growth, the temperate pre-Columbian North America was sparsely populated and guesstimated to be relatively poor (Maddison 2001). Neither is temperate climate absolutely necessary for high income levels, or high growth, demonstrated by modern day Singapore and Malaysia respectively. But we must also remember that geography does not equal climate.

Jared Diamond (1997) forwards a more comprehensive theory on the relationship between geography and economic development. In his influential book *Guns, germs and steel*, he shows how animals and plants suitable for domestication gave different conditions of feeding growing populations and fostering economic growth. He also describes how domesticated animals transferred microbes to their masters, which in the long run built up a system of immunity. These microbes were later decisive in the European victory over the Native Americans, who lacked both large domesticated animals and microbes (ibid., p. 197-199).

Diamond offers us a unique insight into the differences between the Americas, Australia-Oceania and sub-Saharan Africa on one side and Eurasia and North Africa on the other. Of course we have no data from the three former regions and have to guesstimate their standard of living. These guesstimates are mostly based on foreign, often hostile, sources, archaeological evidence or oral tradition.

Diamond's theories have been quantified by Douglas Hibbs and Ola Olsson (2004). Through categorizing the world's nations in terms of biogeography depending on initial numbers of flora and fauna suitable for domestication, they find a substantial correlation of 57 per cent between the logarithm of income and a combined biogeography measurement (ibid., p. 3718-3719).

But their results rest on a series of assumptions that can not be accepted at face value. First of all; North America and Australia have been classified into the West Asia-Europe category, the richest endowed (ibid., p. 3716). There is nothing wrong with this, as these regions received all flora and fauna from their European masters. But why beef producing Argentina or soy bean exporting Brazil is not classified in this category remains up for debate. And even if the correlation would hold today, it does not explain why China was technologically ahead of Europe up until the 15th century (Mokyr 1990, p. 209-218).

In fact, Diamond's overall explanation of differences within Eurasia is not very satisfying. And herein lay the flaw in his theories. His notion of a politically unified China, due to and cohesive land mass (ibid., p. 431-433), is unconvincing. Since its unification by the Qin Dynasty in 221 BCE, China has only been politically unified two-thirds of its history. Uniquely unified compared to other entities of the time, but still shattered compared to a unitary and internally coherent state.

Arguments in a similar line to Diamond's have been forwarded by Marvin Harris (1977), in turn inspired by Karl Wittfogel. He argues that the two major navigable and silt rich rivers, the Huang He and the Chang Jiang, both helped coherence and also required a unitary state for flood control and vast water management projects. But today we know that most of these water projects were managed locally (Mokyr 1990, p. 235), only the major required the state.

Moving on to Europe and England, it is clear that they were assisted by the availability of easily mined coal close to their manufacturing centres (Pomeranz 2000, p. 65-66). And no one can deny that the U.S. benefitted from its vast resources in land, minerals and petroleum. But the mere existence of resources does not cause them to be utilized (Mokyr 1990, p. 160-162). Similarly we have already concluded, in section 2.1, that use of fossil fuels in production did not automatically cause uninterrupted economic growth or technological progress.

Looking at contemporary petroleum producing countries there is no evidence that endowments foster an increased technological ability to utilize those resources. It has actually been suggested that this resource endowment is harmful for those economies (e.g. Landes 2008, p. 468-469). And although many are prosperous in terms of income per capita, this income is unevenly distributed and innovativeness has been sidelined by luxury consumption. Lately, some capital differentiation has occurred, mainly into real estate and financial markets. The most shining example of this is Dubai, which has also been investing in tourism.

Geography is of undeniable importance. Diamond's narrative of the differences between pre-Columbian America and Eurasia serves as an excellent example. But so far we have not seen any evidence that the environment in itself can explain technological progress. Temperate climate, biological endowment, energy or other mineral resources, none have singlehandedly fostered our ability to utilize the energy in our surrounding environment.

If the answer is not found exclusively in nature, then let us now turn to our societies. To what degree can institutions, the norms, regulations and organizations that we have created for ourselves, contribute to our understanding of differences in technology and economic growth?

3.3 Institutions

Although, before we turn to the relationship between institutions and innovations, let us take a look at technology in itself, and ask: Can technology in itself cause further technological improvement?

Innovations can be improvements in technology and new ways of organizing the means of production. All innovations have to build on earlier technology to some extent, whether domestic or foreign. The steam engine by James Watt owes much to the machine by Thomas Newcomen (Mokyr 1990, p. 85). And the *Queen Elizabeth* launch in 1938, the largest steamship ever built, owes much to the 1818 *Savannah*, the first steamship to cross the Atlantic, although she did so mostly by sail. Improvements are often more impressive than the initial invention, just look at the USB-stick. The phenomenon, that innovations lead to further innovation and so on, has been called path dependency (ibid., p. 163).

But high technological levels do not necessarily result in ever more innovations. China demonstrates the point through the widely cited example of the Ming and Qing dynasty, from the 15th to 20th century. China saw major technological advances during the Song dynasty, 10th to 13th century, but then innovativeness slowed in pace (ibid., p. 218-220). Similarly, explaining why technologically backward nations can catch up through the concept of path dependency may be complicated. Technology is not sufficient for further development and only necessary in a very short and immediate term.

Before commencing the discussion of how institutions have determined innovativeness, let us just contemplate that innovations can shape institutions. The cannon helped kings gain control over castle-owning knights and without the invention of paper the extent of modern bureaucracies would be far more limited. The Internet is another perfect example of how technology can shape our norms, our organization of work life and the way we interact with each other.

The concept of institutions is usually defined very broadly. They constitute the norms and values, but also formal regulations within a society (Hay 2002, p. 106). But they can just as well be any form of organization; state, church, etc. Institutions are widely accepted in economic growth theory as crucial for an innovative environment that facilitates growth (e.g. Jones 2002, p. 143-147). Even Joel Mokyr (1990), who stresses the importance of innovations, also attributes differences in innovativeness among the world's nations to institutional arrangements. And Landes (1998), while stressing the revolutionary aspect of the industrial development during the 18th and 19th century, trace the root causes of growth to the institutional setting of Western Europe back to the Middle Ages. But then we must ask; exactly what institutions, historically and contemporary, have been most favourable for innovativeness and economic growth?

Douglass North is regarded as the main pioneer behind the institutional school. Together with Robert Thomas (1977) in their *Rise of the Western World* they see shifting labour to land ratios in Western Europe after the Black Death as vital for the empowerment of the peasantry vis-à-vis the landed nobility. This in turn led to more entrenched property rights and political power for commoners.

Landes (1998) stresses the importance of innovativeness fostered by institutions, and in this sense, largely reaffirms what has been stated by Adam Smith, Max Weber and Douglass North. He contrasts the narrow minded and imperial despotism of Asia with the market friendly and business promoting Western European nation states. According to him, Western Europe fostered a uniquely market and innovation friendly environment were incentives for self-improvement were in place.

This is a fairly uncontroversial notion; more controversial however are his views on the role of the state. Landes adds a qualitative dimension to the role of the state. State intervention was not an inherently bad thing, rather the outcome depended on whether it promoted or discouraged initiative and business. The competing European states were striving for power. They also saw the link between power and wealth, prompting them to stimulate their economies by protecting their own industry while opening new markets abroad.

Meanwhile, the uncontested despots of China did not adapt to a changing world until it was too late. Instead the Son of Heaven and his mandarins would continue a rent seeking behaviour. Trade was prohibited and manufacturing was shunned. Even worse, Landes complains, they shunned Western technology when it was presented to them (ibid., p. 392-397).

By contrast we have Japan; the only nation outside Europe that Landes considers as being on the same page. He even goes as far as to see the island nation as a candidate for independent industrialization (ibid., p. 432). He attributes Japan's positive development to the interest in Western science and enterprise, in other words, Japan's institutional settings (ibid., p. 418-421).

Landes highlights many important aspects of European economic development, especially when it comes to the role of the state. Very revealing examples of the marriage between state and business interests are the chartered monopoly companies. We must not forget that the British Empire, what the realist political scientist Robert Gilpin (1981) calls the greatest empire of all times, was largely built by private enterprises, like the Virginia and East India companies.

And no one can deny that patent rights give rise to incentives to innovate, inventors like Watts became rich on these exclusive rights. A famous example of incentive is the £20.000 rewards for an instrument measuring longitudes, eventually collected by John Harris for his marine chronometer (Mokyr 1990, note 7, p. 69). But as with the Watt steam engine, a patent limits competition and thereby harms further innovativeness (Smil 1994).

However Landes's argumentation becomes somewhat hard to summarize. On one hand he stresses the importance of private initiative and a relatively free market, on the other he acknowledge the importance of state intervention and monopoly companies. His classification of a monolithic and stagnant China and the anarchy of Islam and India provide a very mixed message about the institutions that gave Europe a supposed edge. A "just right"-argument is unsatisfying as it renders little understanding and raises ever more questions.

Central to Pomeranz's (2000) argumentation, that living standards in 18th century Europe and China were quite similar, is that institutional arrangements did not differ in a way that was decisive for their economies. He does not discrediting the importance of European institutions, but instead points to similar institutions or functioning substitutes, in China. Property rights existed there as well and land was easier to sell in China than in Europe (ibid., p. 72-73). Furthermore financial institutions filled their purpose well. They were small scale, but so were pre-industrial requirement and they seem to have (ibid., p. 179-182). And capital ownership does not seem to have been more unequally distributed in China than in Europe (ibid., p. 136-137).

The governments of imperial China provided physical infrastructure on a scale incomparable to any European contemporary. They also went out of their way to enforce competition. In some respect China more resembled an ideal free market than Europe did, e.g. few state monopolies or other privileges (ibid., p. 168-173).

Trade by sea was prohibited, for ships more than two masts, but this legislation was poorly enforced and short lived (ibid., p. 170-172). And Chinese merchants continued to dominate the South East Asian waters for centuries. Instead of failing institutions, Pomeranz attributes the eventual divergence between Europe, i.e. England, and China to domestic and colonial natural resources. This has already been discussed in Chapter 2.

The Indian economy and institutional setting offers a more complex picture. Not politically unified until 1946, there are few common historical pan-Indian institutions. Data on pre-industrial India is sparse as well, but the sources we have has to suffice for the purpose of this study.

David Washbrook (2007) adds an interesting dimension to the debate about the Indian economy, by asking: What made the Indian exporting industry so successful, to the degree that European nations introduced vast protectionist measures, in the 16th and 17th century? This question contrasts to the mainstream research trying to explain India's decline on the economic world stage.

Washbrook first concludes that Indian goods where cheaper due to cheap inputs, rather than a labour force kept in destitution. He also notes that Indian manufactured goods had a quality dimension (ibid., p. 100). Indian cotton cloth held a much higher quality than European; it would take centuries before European manufactures could imitate Indian textiles.

Quite controversially Washbrook attributes part of this superior quality to the caste structure of India (ibid., p. 101-102). Caste forbids anyone to freely seek employment, and this has generally been seen as leading to suboptimal allocations. But constrained within a profession the only mean of self-improvement becomes specializing within that profession. And soon castes and the thousands of sub-castes found ever smaller niches in artisanal manufacturing.

The landholding situation seems worse in pre-industrial India than in Europe or China. Landlessness was a common feature among the peasantry. But the view that these landless labourers were totally powerless might be exaggerated. The rural tenants and landless had some measures of defending themselves in the Mughal era, such as refusing to pay taxes, mass flight or even armed resistance (Habib 1984, p. 8-13). Though these were obsolete strategies in most of the world by that time, and extremely risky, this nonetheless shows that Indian farmers were not as complacent and chanceless as once though.

But 18th century India on a whole seems to have been more unequal than her contemporaries (Pomeranz 2000, p. 136). Luxury consumption was mainly confined to the upper strata of society. However, we know to little about the inequality in pre-industrial India to make any quantitative estimates on how much.

Pre-industrial India was not at all deprived of other institutions deemed as vital for development. Both private business and portfolio capitalism flourished on the subcontinent. And in the Bengal the financial institution of the Jagath Seth wielded immense political power (ibid., p. 176).

The historical account above has given some insights. Incentives for innovation and right to the profits of ones own labour is central when it comes to facilitating innovativeness and economic growth. The same can be said for good governance and state capacity building.

Looking at the world of today it is clear that the quality of institutions matter. Let us, for instance, remember that institutional quality alone explains a solid 67 per cent of the logarithm of GDP in the cross country analysis by Hibbs and Olsson (2004). But when it comes to the question of exactly what institutions are beneficial, we suddenly feel less confident (Rodrik 2003, p. 4-6).

What does economic growth theory have to say about the causes of technologic development? After the importance of technology had been established by Solow, Paul Romer was among the leading researchers in developing the new growth model. Drawing on the microeconomic theories about imperfect competition, the Romer model endogenizes technological progress by the fact that inventors are interested in making a profit (ibid., p. 97). In this model growth will depend on the number of people in the research and development sector and their efficiency, as well as propensity to learn from previous research (ibid., p. 101-103).

The Romer model has gained empirical support, but some components can be debated. For instance, the number employed in the research and development sector has grown steadily in the industrialized economies, but long term growth rates have continued to revolve around 2 per cent.

And, as we have seen above, growth rate in patents and the overall economy do not correspond. My own thought on this development have been presented in section 2.3. And research and development prior to 1850 was not decisive and the relationship between science and technology up to that date is hard to grasp (Mokyr 1990, p. 167-169).

But Romer also saw the ability to learn from others as crucial. In a further developed version of the Romer model, knowledge, learning and education was emphasized. Economic growth is just not a process of developing yourself, but also learning from others. Learning is what the Japanese did from the Americans and Europeans after World War II. And learning is what the medieval Europeans did from the Arabs and the Chinese. Openness to ideas is therefore rightly seen as central to the diffusion of technology (Jones 2002, p. 124-127). This openness is in turn linked to, and often measured as, openness to trade.

The notion that free market is beneficial for growth goes back to Adam Smith and David Ricardo in the 18th century. Free trade, competition and comparative advantages would lead to specialization and optimal resource allocation. The fall of the Soviet Union has given us continued confidence in a market were goods and services are traded freely, instead of provided according to quotas determined by the government. And when comparing import substituting Latin America with export-oriented East Asia, it seems that openness to trade makes all the difference (Gunnarsson & Rojas 2004).

But for openness to translate into a learning process there needs to be some initial level of knowledge domestically. Education was important to all East Asian economies. But other forms of state intervention were also common. Japan and South Korea manipulated the market to favour large exporting companies. China experienced some of its growth even before opening up in the 1970's, the same can be said about India that grew in the 1980's. And when scrapping import substituting policy in the 1990's, Latin American growth has picked up. But this is largely driven by primary commodities and the benefits for the South American manufacturing sector can be questioned (The Economist 2009, p. 17-19).

And based on empirics we can not say that trade free from any state intervention is optimal for the national economy. Not only were the monopoly trading companies, established in the 16th century by many West European nations, vital to their colonial expansion. But the newly established German state in the 19th century played a key role in the construction of its economy (Landes 1998, Cameron & Neal 2003).

Landes (1998) arguments that state intervention may be benign, this may be controversial to those economic historians specialized on Western economic history. But for students of the East Asian economies this is anything but a surprise. Japan was the first non-European nation to industrialize and the state held a key role in promoting industrial development. Since then, all of the so called Asian tigers have had strong influxes of state intervention (Stiglitz & Yusuf, eds. 2001). The latest, and largest, addition to the Asian miracle economies is China, were despite some market reform, the state still plays an immense role (e.g. Naughton 2007), something many Western scholars fail to appreciate.

But from all these examples we should hesitate to draw the conclusion that state intervention per se is beneficial. Policymakers make mistakes as easily as businesspeople, and corruption and entrenched interests of the elite often lead to suboptimal choices.

Property rights are seen as the most convincingly beneficial of institutions (North & Thomas 1977, Landes 1998). Looking at the Soviet Union, or modern day North Korea, it is evident that people loose interest in promoting productivity if they in no way benefit from their efforts.

However, again turning to pre-industrial China, property rights are not sufficient for long term economic development. A more recent example of this is Latin America. In the early 20th century South America was seen as promising region, but stagnated from the middle of the century (Gunnarson & Rojas 2004). And despite being most in line with the recommendations of the neoliberal

Washington consensus in the 1990's, this did by no means help the continent towards a higher growth path (Rodrik 2003, p. 6).

Even if formal property rights are not necessary or sufficient for growth and development, it is clear that some form of incentive is needed. One example of incentive structure is the Household Responsibility System in China during the 1970's which enabled farmers to manage their own land (Naughton 2007, p. 241-242), and even sell part of their produce. This created incentives for improvement. Later Township and Village Enterprises were introduced, where small scale business was promoted, with the same results (ibid., p. 271-275). But this was a far cry from formal property rights in the conventional sense (Rodrik 2003, p. 8), not until today is the Chinese government contemplating to let farmers "sell their land", officially owned by and rented from the state.

Dani Rodrik (2003) stresses that it is extremely difficult to isolate any specific set of institutions that leads to the fulfilment of economic growth. Neither has this study been able to pinpoint any specific institution that has determined a high growth path, but we can still, quite straight forward, define the universal principles that benefit growth. And we thereby can also specify what properties we want beneficial institutions to have.

From the account above we can conclude, that we want institutions which create some form of incentive. This often through some rudimentary form of right to the profit of ones labour and some rudimentary form of rule of law (ibid., Table 6). Moreover, which has not been discussed much in this thesis, but is nonetheless important, we have to have some degree of macroeconomic stability (ibid., Table 7). A propensity to learn from others is also clearly beneficial. But how these institutional properties are achieved can vary enormously between nations. Although we can take some comfort in that the main point of Rodrik's paper (ibid.), is to show that neo-classical growth theory can actually be quite more flexible than some give it credit to be. From our discussion so far we must hope that neo-classical growth theory can live up to such attributed flexibility.

If we were to continue by avoiding discussion of specific beneficial institutions and instead focusing on the beneficial properties they might render, we still would have to recognize that many of those economically beneficial properties have been achieved against the interest of entrenched elites. What then has caused, or forced, policy makers to promote them? This question is central to our understanding of institutions, innovativeness and economic growth. When closer examined it actually asks: What has caused the creation of institutional settings that has promoted economic growth?

One very simple, albeit unorthodox, explanation might be; that some people are more rational than others, perhaps not so much by birth as by social context. This line of thought exists in the works of Max Weber, David Landes, and many, many others.

I would like to state, once and for all, that to the question whether rationality comes with place of birth or culture, the answer is: No! Not because of any ideological conviction on my behalf, but because historical evidence pushes in another direction. The very nature of rationality is conditional. And what makes perfect political and economic sense in one society can make absolutely no sense for the other. Likewise, mismanagement, entrenched interests and corruption or other factors that interferes with rational acting are worldwide phenomena. Economic and political rationality is better seen as an effect of development than a cause. In this sense rationality is just another institution that needs to be explained.

But perhaps other properties may be inherited by cultural setting. Let us briefly examine the role of culture. Cultural properties have been forwarded as the explanation to industriousness and economic growth, spearheaded by Max Weber. He sees the Calvinist work ethic as crucial to the economic development of the Netherlands and Switzerland (Landes 1998, p. 210-215). And in the case of Calvinists this has undoubtedly been the case. Similarly culture, in the form of the Protestant-Catholic divide, has been forwarded as an explanation to the stagnation of Latin America and the difference between Northern and Southern Europe.

But the economic relationships change over time. Just as early modern Calvinists in Holland or Switzerland were poor, but hardworking and increasingly rich in their days, so are the Confucians, like in China of ours. And culture can also change or be adapted over time. Japan is an excellent example of where some parts of the institutional arrangements have changed to better fit the international economy, while other factors have remained intact (e.g. Landes 1998). Culture makes an important contribution to economic development, but this is a far cry from ascribing culture any overall explanatory properties. Just as with rationality culture constitutes an institutional arrangement that need to be explained.

This explanation is not easy to find an answer to in contemporary literature, due to the fact that the question has not been examined in detail. This may seem surprising as institutions have been given such an enormous explanatory value.

However the father of economic institutionalism Douglass North does not disappoint in this regard. His answer is very straight forward (North 1993, p. 75): "[C]ompetition is key to institutional change…". And when examining other authors within the field of economic history it appears to be a wide consensus around competition as the driving force behind institutional development (e.g. Mokyr 1990, Diamond 1997, Landes 1998).

And Charles Jones, as representative of economic growth theory seems to share the above stated view (Jones 2002, p. 149), by quoting Mokyr (1990). How competition has shaped institutional arrangements will be presented and examined in the following chapter.

4 Contextual Dynamism

In what way has competition affected the quality of institutions? The argument goes that competing states fostered competing markets, entrenched property rights and business promoting state intervention. Even those researchers who do not explicitly focus on institutions, e.g. Diamond (1997), ascribe explanatory properties of economic development to competing states. As a consequence Europe, with its constantly feuding nation states, was alone in fostering the modern institutions.

The logic behind this is that the power struggle led European states to promote institutions that furthered exploration and innovation (Mokyr 1990, p. 78-80); such as monopoly trading companies, patent systems and different forms of property rights. Furthermore, the continuous need for financial resources for warfare forced the states to turn to their commoners who in turn were granted more solid rights, creating the incentives discussed above.

Mokyr (1990, p. 78-80) sees competition as vital for innovativeness. Diamond (1997, p. 430-432) also sees competition between European states as vital to their economic and military superiority. Implicitly or explicitly there is a large support for this line of thought concerning European military and economic dominance. But what can be said about the world outside Europe?

In China there is some support for this argumentation as well, not in imperial China, but in its antiquity. We must remember that the Middle Kingdom was not always unified. Before the Qin dynasty, and a third of the time afterwards, China was divided into warring states. During these periods those competing states granted extensive rights to their citizens. This was later rolled back with the rise of the Qin dynasty and the first Chinese Empire (Tin-Bor-Hui 2001, p. 373-374).

A school book example of the damaging effects of a centralized state is the travels of admiral Zheng He’s during the early Ming dynasty. With a vast fleet of enormous ships the Chinese expeditions criss-crossed the Indian Ocean between 1405 and 1433 (Marks 2002, p. 65-69). But once travels fell out of imperial favour no more expeditions were sent, the shipbuilding industry collapsed and sea travel stagnated. By contrast, Europeans had no such imperial authority. Keep in mind that Christopher Columbus got five refusals before getting a final endorsement from the Catholic majesties of Spain (Diamond 1997, p. 429). The Chinese maritime initiative was destroyed by only one refusal.

During later imperial history, the Ming and Qing dynasty, China was and remained unified and unchallenged (Mokyr 1990, p. 231). The Chinese imperial state seldom had any fiscal deficits and therefore little dependence on bankers and merchants (Pomeranz 2000, p. 173). Some would state this independence as the reason why merchant had a lower status in China than in Europe. And it has been suggested that it was this low status that hampered China's economic and technological development (Mokyr 1990, p. 230).

From the 15th to the 17th century Japan was engulfed in civil war, where competing Daimyo-states fought each other fiercely. To fill their ranks the *daimyos* used commoner recruits, called the *ashigaru*, mostly armed with muskets. In 1600 the island nation, unified under the Tokugawa Shogunate, wielded more muskets than any other nation on the globe (Diamond 1997, p. 260). But once unified by the Shogunate, Japanese *samurai* started seeing muskets more as a danger to their own supremacy, not as a potential mean for conquest. As a consequence musket production stagnated. Although muskets were officially banned in the mid-17th century, it has been argued that the lessons learnt from their manufacturing served Japanese production well during the Meiji restoration (Landes 1998, p. 412).

All the above examples from China and Japan, and almost every aspect of European economic history, seem to point in the same direction: Competition did matter for the creation of institutions beneficial for technological development and economic growth. The Asian nations benefitted as long as there was competition, but stagnated when they were, or thought they were, unthreatened.

But when examined closer these widely accepted, and theoretically appealing, arguments do not add up with historical realities. Competition thrived in the Chinese domestic market during imperial times as well; the state ran few monopolies that disrupted private business (Pomeranz 2000, p. 171-173). If logic was true, that competing states foster innovativeness, it also seems odd that the Chinese inventiveness peaked either during the Han (Smil 1994, p. 61) or the Song dynasties (Mokyr 1990, p. 209-218). This despite the fact that China during there periods was a unitary political entity, at least during the Song.

Also, the view of a negative effect by the low status of merchant during the Ming and Qing eras has been refuted lately. Merchants actually seem to have gained some societal status during those times (ibid., p. 231).

And Japan does not seem stagnant during the Tokugawa Shogunate. On the contrary its GDP per capita has been estimated to have grown during that period (Maddison 2001, p. 253-254). And the government of the Shogunate and Japanese society was more acceptant of European technology than we previously might have thought (Landes 1998, p. 404-406).

In contrast to imperial China, but like pre-industrial Europe, India consisted of competing states. Yet none of these did render institutions or institutional properties beneficial for economic growth. And none of these states succeeded in creating a sense of nationhood. Even the Hindu Marathas under Shivaji Bonsle did not achieve, or even attempt, a sense of nationhood. Instead the Marathas power relied on mass armies led by landlords (Habib 1984, p. 24-25), primarily from their own caste.

And even examples from Europe itself disprove the logic that the amount of competition determines institutional outcomes. Let us ask: Where would we expect the most development among militarily competing states? The answer would of course be: In military technology. But when examining the pace of change in pre-industrial European armament the sluggishness is striking (Smil 1994, p. 184). During the 100 years between 1500 and 1650 armies were dominated by the pike and shot formations. Pikes were slowly substituted for muskets as the latter improved. And from the 18th century up until the American Civil War between 1851 and 1856, the musket and twelve pound cannons remained the main weaponry.

However, there is no doubt that superior muskets and infantry tactics gave Europeans an advantage towards non-European nations. Those who opposed seldom measured up. How could they, as they either depended on European armament and military knowledge or ignored it?

We can now see that pinpointing the degree of competition seen as beneficial is extremely difficult. Landes's (1998, p. 505) categorization of China as ecumenical and India and Islam as chaotic highlights this difficulty.

Our historical observations have not made us wiser. The Chinese hegemon had traders and manufacturers operating closer to perfect competition than those in Europe, and China had economically beneficial institutions, but technological development still stagnated. Japan went from decentralized to centralized, but experienced at least some improvements. And the competing Indian states did not render improved institutional arrangements. Europe itself consisted of competing nation states with, to various degrees, imperfect markets.

But maybe this is an interesting hypothesis: That it was not competition per se, but imperfect competition that led Europe into developing institutions that fostered innovation?

The importance of imperfect competition in economic theory is nothing new and was applied within economic growth theory by Paul Romer. It was first brought to attention by Joseph Schumpeter in 1942 in his *Capitalism, Socialism, and Democracy* (Pepall, Richards and Norman, 2008, p. 573). He believed that the larger the firm was, the more would it invest in research. Let us here, for a brief moment, turn to microeconomic theory.

There is a formula that estimates the share of sales that will be diverted to research and development by an individual firm (ibid., equation 22.8, p. 585). Without describing the technicalities of the market concentration formula, it states that the propensity to conduct research and development increases with the firm's market share. There is also some empirical support for the hypothesis that imperfect competition fosters incentives for innovation (ibid., p. 585-586).

The logic behind this is that imperfect competition gives incentives as it enables long term profits for an entrepreneur, as well as an innovator. But at the same time there is a major flaw in the microeconomic reasoning.

What incentives does a monopoly have to improve its products? Compare with the strong market position in the early 20th century car manufacturing of Ford, as they announced that they offered only black cars to their costumers (Landes 1998, p. 548). And the Watt's steam engine patent, issued in 1769 actually made technological progress significantly slower, up until 1800 (Smil 1994, p. 161-164). If you are sole actor on any market, why offer improvements? And although the imperfect competition hypothesis has a lot of merit, it perhaps has more so during the industrial era and in the future than in the past.

Despite these doubts we can conclude that if any competition really did matter for institutional and technological development – it is imperfect competition. But this does not make us any wiser, as market imperfections are everywhere.

Outside of Europe competing states did not foster a sense of belonging or the same institutional and technological development. India did not reap the same institutional benefits of having states competing for power. At the same time China seemed to have fostered market competition and other economically sound institutions, but did not reap the benefits in terms of sustained growth.

To understand the development of institutions I would like to suggest a more qualitative approach to competition. I call this contextual dynamism. We should stop trying to define the world as competing versus non-competing. Every nation, organization, or individual for that matter, faces some sort of competition. Instead we should look at what kind of competition that faces the society we are trying to understand.

It is not true that the late imperial Chinese dynasties were uncontested. The Ming faced a constant threat from the Mongols, prompting them to build the Great Wall. This was only finally solved by the Qing, who were Manchus, and made heavy use of cavalry just like the Mongols.

The Qing dynasty was expansionary and had to face the Central Asian nations. The vast expanses of Central Asia were best dominated by swift cavalry, light infantry and light artillery. And this was exactly the composition of the Qing army. The threat from the European appeared less acute. After a series of defeats during the mid-19th century, China attempted to answer in the early 20th century, but then their Japanese enemies were already way ahead.

The Indian states had a whole other set of enemies, mostly other Indian states with similar technology and tactics. When they were in need of advanced European equipment it was often less expensive and more beneficial to buy the gunners with the guns. But facing enemies on almost every flank the Indian states became a cacophony of different military technologies. In the third battle of Panipat in 1761, the Marathas used war elephants and bowmen alongside European style infantry and bought French smoothbore artillery.

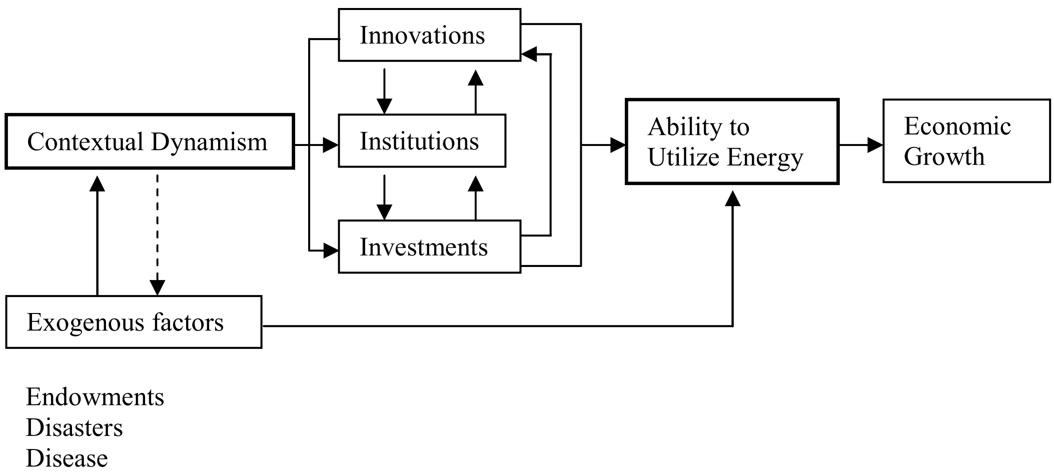
These state-military parallels are far from perfect in understanding economic behaviour, but also firms have to work and compete within a special national and cultural context. The Japanese *keiretsu* or the Korean *chaebols* compete on different terms than those facing American or European firms.

The contextual dynamism, or the form of competition, that a society faces is affected by exogenous factors, such as a society's geographic and strategic position. The institutional path chosen by, or forced upon, any nation will depend on what the neighbouring societies look like. The institutional path can also shift through epic events, like the bubonic plague in 14th century Eurasia or the small poxes in 15th century America, or rapid climate change. But contextual dynamism also leaves room for the internal dynamics of a society.

With the concept of contextual dynamism, I do not want to deny that competing states were important for the European institutional and technological development. Patents and trade monopolies were created to enhance the national wealth and thereby the capabilities to wage war. The financing of constant warfare sparked demands by commoners for improved political status and more advanced property rights. But through the approach of contextual dynamism we can acknowledge those events as specifically European, without generalizing those conclusions to the rest of the world.

My main point here is that; different forms of competition have rendered different forms of institutional settings. This is not nihilism or relativism; it is simply an appeal to economic historians to acquire more detailed knowledge about the world's different civilizations before making swooping generalizations. Similarly economists must learn the details of any nation's specific institutional setting before making policy recommendation. This can not, and should not, be too much to ask for.

Figure 3: A Graphic Summary of the Thesis's Arguments



The figure above summarizes the conclusions of this study and highlights my own contributions to the contemporary fields of economic history and economic growth theory.

Ultimately contextual dynamism, partly affected by exogenous factors, determines the institutional outcomes. Those institutions in turn determine the propensity to innovate and invest. Innovations and investment, in capital and infrastructure, determines our ability to utilize energy. Finally it is the ability to utilize the energy in our surrounding environment that determines long term economic growth.

5 Conclusion

This thesis is a consequence of my unsatisfaction with contemporary economic history and economic growth theory to explain the high growth trajectory that we have experienced since the industrial revolution. I have argued that the neglect of energy has limited our understanding of this process. And while energy is not sufficient to explain the expansion in world economy and population, it is however absolutely necessary. Without the energy resources the world economy would have run into diminishing returns, no matter how many revolutionizing innovations we would have had or how good our institutions would have been.

On the other hand, it is just as clear that energy resources alone would not have lifted world economy without the technology to utilize them. Only together were these two factors sufficient to explain the industrial revolution and growth take-off. Technology in turn is affected both by natural environment and previous technological achievements.

But ultimately technology and innovativeness have their root causes in benign institutional arrangements. However, I have argued that the institutions seen as desirable do not always work and that indisputably beneficial institutions are hard to pinpoint. It is much easier to define what institutional properties we see as desirable, but how these have been achieved through time and space varies enormously.

Variations in institutional outcomes are determined by competition. Although I have argued that competition in itself is not sufficient to explain the diverse institutional outcomes. Any form of competition must be seen in its right context. Only the through the concept of contextual dynamism can we understand the different institutional and economical paths of different societies and civilizations in the world. And without such an approach our ability to give adequate policy recommendations will also be limited.

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Appendix 1

Correlation between GDP and Energy Consumption for Individual Countries

In the equation below lngdp represents the logarithm of Gross Domestic Product per capita, in chain prices, (http://pwt.econ.upenn.edu/) and lnenergy represents the logarithm of energy consumption in kg of oil equivalent per capita (www.worldbank.org). The method used is ordinary least squares.

*lngdp = c(1) + c(2) * lnenergy*

Rich Countries

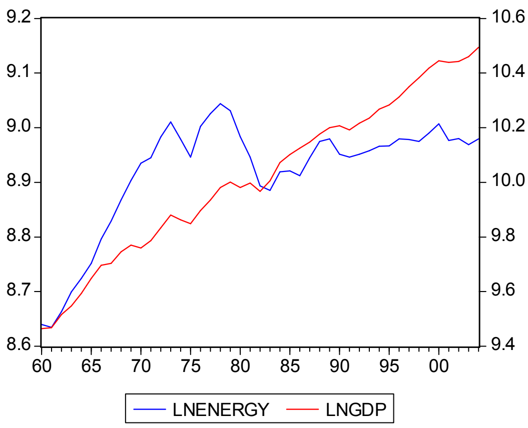
The U.S.: Energy and Gross Domestic Product

Date: 07/23/09 Time: 16:26
Sample: 1960 2004
Included observations: 45
LNGDP=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-8.187044	2.609195	-3.137766	0.0031
C(2)	2.041302	0.292529	6.978121	0.0000

R-squared	0.531050	Mean dependent var	10.01900
Adjusted R-squared	0.520144	S.D. dependent var	0.294840
Durbin-Watson stat	0.039764		

Correlation: U.S.: Energy and GDP



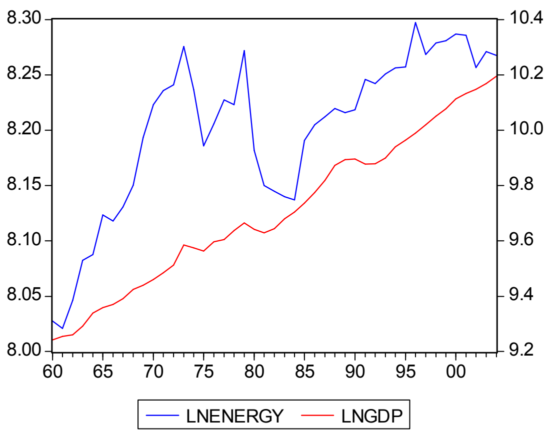
The U.K.: Energy and Gross Domestic Product

Date: 08/17/09 Time: 00:57
Sample: 1960 2004
Included observations: 45
LNGDP=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-15.56648	2.869765	-5.424304	0.0000
C(2)	3.081548	0.349896	8.807034	0.0000

R-squared	0.643342	Mean dependent var	9.706676
Adjusted R-squared	0.635048	S.D. dependent var	0.278424
Durbin-Watson stat	0.201867		

Correlation: U.K.: Energy and GDP



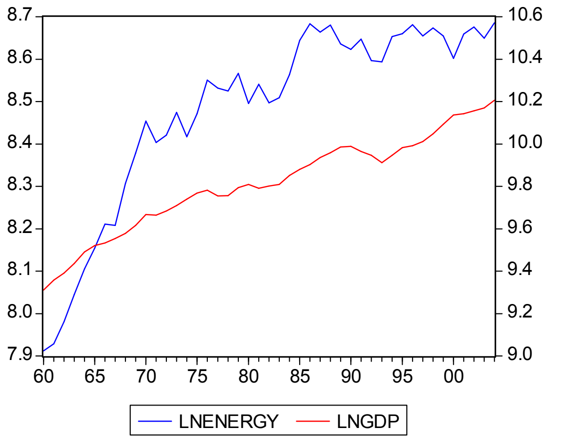
Sweden: Energy and Gross Domestic Product

Date: 08/17/09 Time: 01:10
Sample: 1960 2004
Included observations: 45
LNGDP=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	1.632366	0.507498	3.216500	0.0025
C(2)	0.964387	0.059816	16.12269	0.0000

R-squared	0.858058	Mean dependent var	9.811891
Adjusted R-squared	0.854757	S.D. dependent var	0.229579
Durbin-Watson stat	0.225960		

Correlation: Sweden: Energy and GDP



Countries that have Become Richer

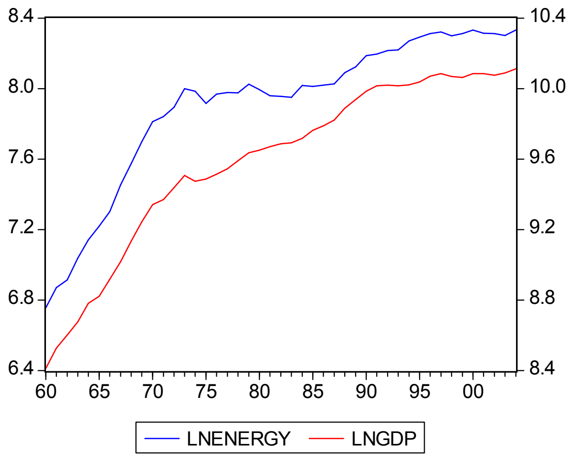
Japan: Energy and Gross Domestic Product

Date: 07/23/09 Time: 16:34
Sample: 1960 2004
Included observations: 45
LNGDP=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	0.832159	0.249702	3.332603	0.0018
C(2)	1.107726	0.031543	35.11850	0.0000

R-squared	0.966309	Mean dependent var	9.588491
Adjusted R-squared	0.965526	S.D. dependent var	0.487999
Durbin-Watson stat	0.128964		

Correlation: Japan: Energy and GDP

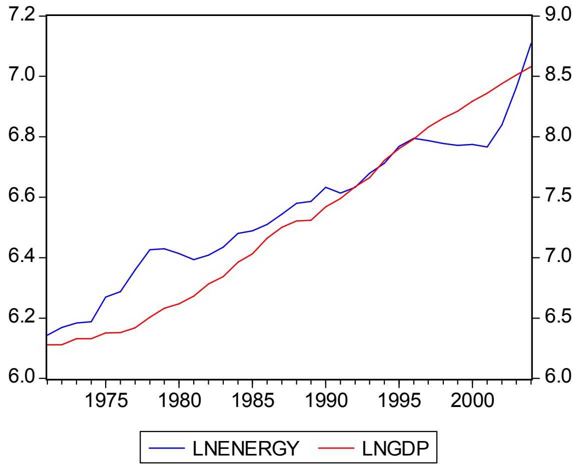


China: Energy and Gross Domestic Product

Date: 07/23/09 Time: 16:43
Sample: 1971 2004
Included observations: 34
LNGDP=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-13.02264	0.947359	-13.74626	0.0000
C(2)	3.098285	0.144396	21.45680	0.0000
R-squared	0.935011	Mean dependent var		7.291689
Adjusted R-squared	0.932981	S.D. dependent var		0.761957
Durbin-Watson stat	0.386045			

Correlation: China: Energy and GDP

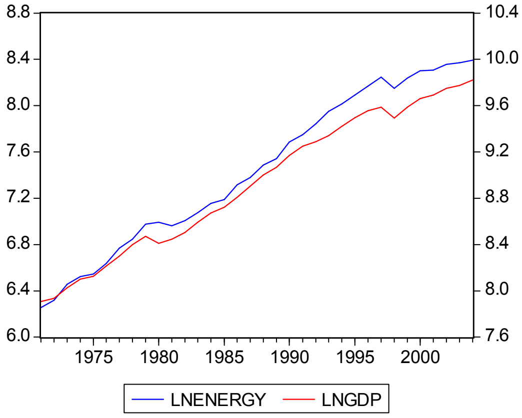


South Korea: Energy and Gross Domestic Product

Date: 08/17/09 Time: 01:15
Sample: 1971 2004
Included observations: 34
LNGDP=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	2.292102	0.069790	32.84307	0.0000
C(2)	0.890481	0.009329	95.45279	0.0000
R-squared	0.996500	Mean dependent var		8.926321
Adjusted R-squared	0.996391	S.D. dependent var		0.613583
Durbin-Watson stat	0.663489			

Correlation: South Korea: Energy and GDP



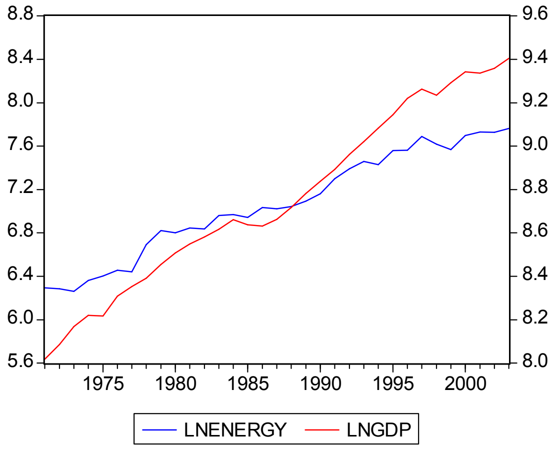
Malaysia: Energy and Gross Domestic Product

Date: 08/17/09 Time: 01:20
Sample: 1971 2003
Included observations: 33
LNGDP=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	2.773736	0.149588	18.54248	0.0000
C(2)	0.846528	0.021119	40.08422	0.0000

R-squared	0.981072	Mean dependent var	8.756080
Adjusted R-squared	0.980461	S.D. dependent var	0.416573
Durbin-Watson stat	1.123994		

Correlation: Malaysia: Energy and GDP



Poor Countries

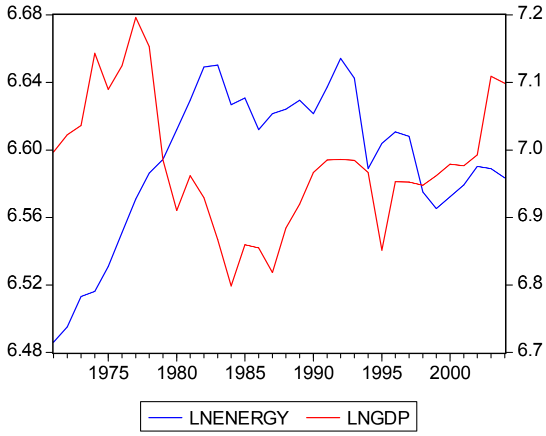
Nigeria: Energy and Gross Domestic Product

Date: 07/23/09 Time: 16:51
Sample: 1971 2004
Included observations: 34
LNGDP=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	14.91687	2.146857	6.948236	0.0000
C(2)	-1.204149	0.325636	-3.697835	0.0008

R-squared	0.299382	Mean dependent var	6.978320
Adjusted R-squared	0.277488	S.D. dependent var	0.097631
Durbin-Watson stat	0.620122		

Correlation: Nigeria: Energy and GDP



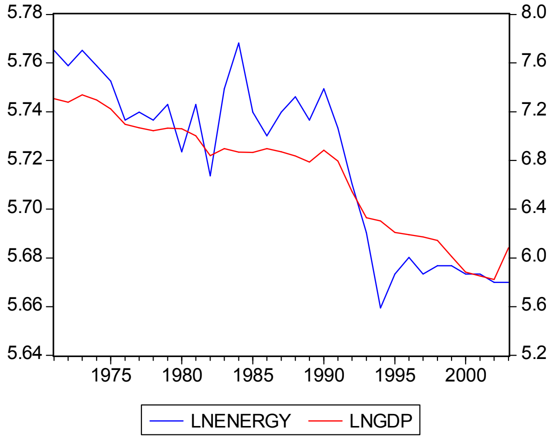
The Congo: Energy and Gross Domestic Product

Date: 08/17/09 Time: 01:41
Sample: 1971 2003
Included observations: 33
LNGDP=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-64.70588	4.982453	-12.98675	0.0000
C(2)	12.48257	0.871056	14.33038	0.0000

R-squared	0.868844	Mean dependent var	6.693260
Adjusted R-squared	0.864613	S.D. dependent var	0.473518
Durbin-Watson stat	1.006998		

Correlation: The Congo: Energy and GDP



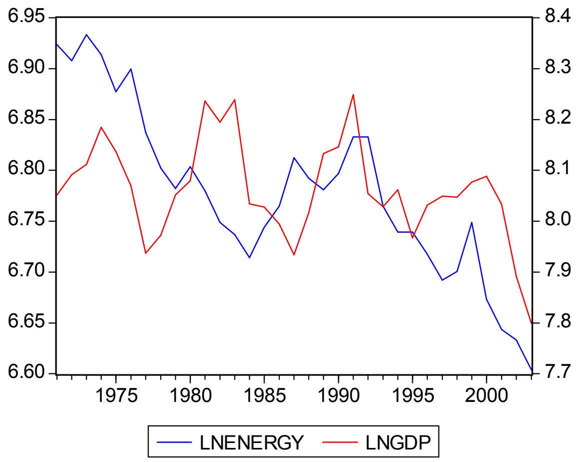
Zimbabwe: Energy and Gross Domestic Product

Date: 08/17/09   Time: 01:56
Sample: 1971 2003
Included observations: 33
LNGDP=C(1)+C(2)*LNENERGY

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	4.939154	1.308074	3.775898	0.0007
C(2)	0.460625	0.192972	2.387006	0.0233

R-squared	0.155263	Mean dependent var	8.061301
Adjusted R-squared	0.128013	S.D. dependent var	0.098462
Durbin-Watson stat	0.876238		

Correlation: Zimbabwe: Energy and GDP



Appendix 2

Correlation between Urbanization and GDP

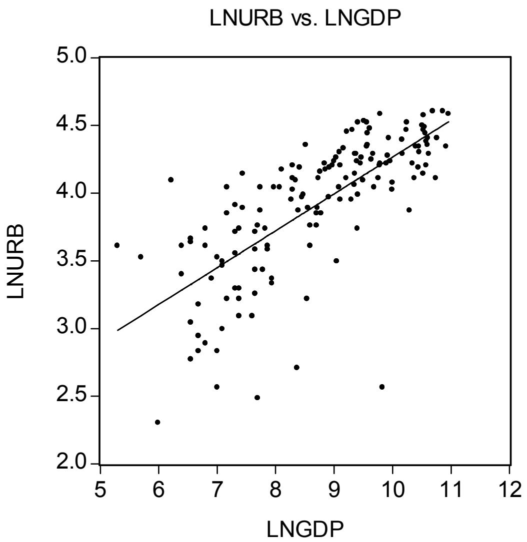
Table 4: Cross Country Comparison: Urbanization and GDP

Date: 07/23/09 Time: 15:45
Included observations: 151
LN_URB=C(1)+C(2)*LN_GDP

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	1.543948	0.186060	8.298115	0.0000
C(2)	0.272273	0.021139	12.88041	0.0000

R-squared	0.526841	Mean dependent var	3.912459
Adjusted R-squared	0.523666	S.D. dependent var	0.505094
Durbin-Watson stat	1.886391		

Figure 2: Correlation: Urbanization and GDP: Cross Country



While there is solid evidence for correlation between urbanization and GDP per capita in a cross country study, when we examine the same correlation for nations below the $2.000 per capita line we find virtually no correlation.

No pre-industrial country reaches above the $2.000 per capita line. This highlights the problem I see with Maddison relying so heavily on data on urbanization ratios (e.g. Maddison 1997, 2001).

Table 4: Cross Country Comparison: Urbanization and GDP
(below the $2.000-line)

Date: 08/21/09 Time: 00:02
Sample: 1 37
Included observations: 37
LNURB= C(1)+C(2)*LNGDP

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	2.581342	0.980790	2.631900	0.0125
C(2)	0.116484	0.142147	0.819462	0.4181

R-squared	0.018825	Mean dependent var	3.382901
Adjusted R-squared	-0.009209	S.D. dependent var	0.435334
Durbin-Watson stat	1.954323		

Figure 2: Correlation: Urbanization and GDP: Cross Country
(below the $2.000-line)