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Path Dependence in Energy Systems

and Economic Development[1]

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Abstract

Energy systems are subject to strong and long-lived path dependence, due to technological, infrastructural, institutional and behavioural lock-ins. Yet, with the prospect of providing accessible cheap energy to stimulate economic development and reduce poverty, governments often invest in large engineering projects and subsidy policies. Here, I argue that while these may achieve their objectives, they risk locking their economies onto energy-intensive pathways. Thus, particularly when economies are industrializing, and their energy systems are being transformed and not yet fully locked-in, policy-makers should take care before directing their economies onto energy-intensive pathways that are likely to be detrimental to the long run prosperity of their economies.

Introduction

In the late 1980s, economists were offered a theoretical explanation for why markets can fail to move towards the socially optimal outcome, even in the long run[1]. Building on the classic example of the QWERTY keyboard and other case studies, such as the dominance of inferior VHS videotapes, an explanation was given for how increasing returns to scale, as well as learning and network effects, could lead an economy (or system, more generally) to be faced with multiple potential outcomes and how the eventual outcome depended on circumstances in the early history of particular technologies[2]. In other words, history mattered, and, if the 'wrong' path was followed, the economy could be stuck in a socially sub-optimal outcome.

[1]. I would like to thank Fergus Green, Andreas Kopp and Nick Stern for discussions on the topic. Financial support from the ESRC is gratefully acknowledged.

Shortly afterwards, an example was given of path dependence within an energy system that showed how water pressurised nuclear reactors became the dominant technology through a series of historical coincidences[3]. Then, studies began to outline the implication of technological lock-ins for addressing climate change[4-6]. After a quieter decade on this front, the recent explosion in long run and historical research has offered a number of new examples of path dependence.

A better understanding of path dependence in energy systems is critical and urgent for two reasons. First, current efforts to stabilise the climate require unlocking industrialised economies from their existing fossil fuel energy systems[6]. Second, the period of global economic growth in the late 1990s and early 2000s was associated with a wave of industrialisation in a number of developing economies. Industrialisation is a time of heavy investment creating lock-ins and ultimately path dependence. Thus, it is critical and urgent that lock-ins and path dependence be better understood, their implications identified and strategies to deal with them formulated.

Given that the role of path dependence in unlocking from the current fossil fuel-based system is receiving new attention[7-9], the purpose of this Perspective is to pull together examples related to energy systems, and explore their interlinkages with economic development and the energy intensity of the economy, drawing attention to the potential burdens from locking-into an energy-intensive economy. My aim is to connect the micro-studies of path dependence with the macro-level implications. Because of the scale of the topic, this Perspective can only offer a few examples from a cross-country and historical viewpoint, in the hope of stimulating further research and debate.

Energy Demand and Economic Development

Access to cheap energy is seen to be fundamental for economic development and for reducing poverty – especially with more than one billion people globally currently without access to electricity[10,11]. In parallel, the expansion of an energy-related physical infrastructure has frequently been critical to the provision of abundant cheap energy[12]. Thus, there tends to be a positive feedback between energy resources, infrastructure and industrial development, locking an economy into specific consumption patterns[13-15].

Long run demand for mobility (and its associated energy consumption) at a given level of per capita income is heavily determined by the urban and national transport network[16,17]. The expansion of transportation infrastructure is typically seen to generate additional 'induced demand', principally by initially lowering the cost of travel due to shorter travel times[18]. It is associated with urban sprawl and often used as an argument against expanding road infrastructure. Certainly, in the USA, increased provision of roads appears unlikely to do much to relieve congestion, though it does increase total amount of travel[19]. Thus, all things being equal, greater transport infrastructure is likely to increase the energy intensity of the economy and lock it into a higher energy intensity pathway[20].

A form of induced demand is also likely to occur in other energy-related engineering projects, such as large-scale hydroelectric dams and nuclear power stations, which create sudden and dramatic increases in power supply. Such energy projects can also leave long-term legacies of local poverty, distributional inequality and environmental damage (see BOX 1). However, once completed, these megaprojects do tend to offer low marginal costs of energy production. For the economy's development, reducing the constraints on energy use and the associated prices is clearly seen as desirable. This drives up energy consumption, putting the economy on a new (if energy-intensive) path. Commentators have argued that mega-projects are often implemented to ambitiously transform society[21,22].

Yet, many[23-25] recommend against developing economies investing in energy mega-projects, because their costs are consistently under-estimated and, in many cases, they do not to offer positive cost-benefit analyses. Moreover conventional cost-benefit analyses struggle to quantify the unintended and non-linear costs and benefits of projects[21]. Furthermore, the lure of cheap and abundant power can seduce economies into energy-intensive behaviour that eventually makes it vulnerable to energy shortages[26,27] (see below).

A crucial point is that the role of energy services on economic development is likely to change at different phases of economic development[28]. For instance, during the Industrial Revolution, the influence of declining energy service prices on economic growth appears to have changed greatly over time[29]. Increases in energy use and improvements in energy efficiency were the main sources of economic growth in the nineteenth and early twentieth centuries, but not in the second half of the twentieth century[30]. Thus, one lesson learned might be that, if timed and managed correctly (e.g., at the right phase of economic development, and tied-in with policies promoting structural transformation – as occurred in South Korea in the 1960s and 1970s[31]), judicious infrastructure projects reducing energy prices can help kick-start the economy, but, at the wrong time or if poorly managed, they will only feed through into inefficient energy consumption, and large debts.

Locking-into Energy-Intensive Systems

Certainly, there are signs of energy-intensive economic development today. Given that the efficiencies of energy technologies have improved dramatically over the last two hundred years[32] and played a role in declining energy intensities (that is, the energy use to GDP ratio) [33,34], one study set-out to identify whether currently developing economies are less energy-intensive than present day OECD countries, when they were at similar levels of economic development[35]. It identified three factors influencing their energy-intensities: more efficient technologies today; more exporting in developing economies today; and more consuming of energy-intensive bundles today. The first of these factors would drive down energy intensity, while the other two clearly increase it. However, the study found evidence of increased energy-intensity overall, arguing that these two latter factors have outweighed the first factor[35]. In other words, today's developing economies appear to be following energy-intensive pathways[36,11], potentially associated with technological, infrastructural, behavioural and institutional lock-ins.

Although infrastructure is arguably the most powerful and long-lasting lock-in, defining the geography of a country and the behaviour of an economy for centuries and even millennia[37,38], the most commonly referred-to lock-ins relate to technologies (see BOX 2). Yet, evidence is also emerging of behavioural lock-ins associated with energy production and consumption. One study finds that path dependence (i.e. persistent behaviour sixty years after conditions changed) is responsible for 60% of total coal-fired power station capacity in certain counties in the USA[39]. Two other examples of path dependence show that the proximity to nineteenth century coal mines in the US and the UK has been associated with less-developed entrepreneurial cultures today[40,41]. Another study indicates that temporary rationing policies can have long term effects on behaviour[42]. In that work, extreme electricity shortages in the Brazilian South-East due to low rainfall were shown to force regional authorities to introduce strong demand-side management programmes that altered habits, evident ten years later. In other words, factors (including policies) can drive consumption down, as well as up.

Often policies can be influenced by the institutional and market structure, which becomes the source of the path dependence. Although more research is needed[43], there is likely to be a correlation between the size of corporations, market power and energy system lock-ins. Large companies and more concentrated industries will have greater financial wealth and will be better coordinated to lobby governments (also known as regulatory capture or rent-seeking) to protect a particular energy system[44]. Certainly, where nuclear power is dominant, and the electricity industry is both highly concentrated and connected with related policy decisions, such as in France, it is harder to move towards liberalised and competitive markets and potentially different energy systems[45].

Even more evident was the dominance of energy-intensive companies in the $1.5bn spent on lobbying associated with the failed US climate policy known as the Waxman-Markey Bill[46]. In 2014, eight of the top ten largest companies in the world (as measured by sales revenue) were oil or car companies[47]. In other words, there is (and has been for a long time) considerable financial and political power to support the fossil fuel status quo[48]. More generally, the market power of energy companies can heavily influence the degree of lock-in of a particular energy system.

Subsidies, which are lobbied for by energy companies, play a critical role in placing economies on energy-intensive pathways – though they are often introduced to boost production and employment on the supply-side and reduce fuel poverty on the demand-side. As shown in Figure 1, there is a close positive relationship between per capita subsidies and per capita consumption of petroleum, natural gas and coal (for more than fifty energy-producing developing and industrialised economies) – though causality can certainly not be attributed because of the complexity of disentangling the interaction between economic development, production, consumption and energy prices. Thus, the existence of US$4.6 trillion of global fossil fuel subsidies (including the external costs of energy production, distribution and consumption[49]) in 2013 (or 6% of global GDP) is associated with higher per capita consumption, and may be linked to lock-ins favouring energy-intensive production and consumption. Thus, the full impact of removing subsidies will probably take many decades (if not centuries) to change.

As an example, in 2013, post-tax subsidies in the USA amounted to US$350 billion for petroleum products, US$78 billion for natural gas and US$178 billion for coal – thus, US$605 billion of subsidies on fossil fuels, equivalent to 3.75% of the USA's GDP[49]. These subsidies have undoubtedly been in place for a long time - at least 100 years for the fossil fuel industry in the USA[50] – locking the economy into an even higher level of energy intensity than it would be without subsidies. It has been argued that American policies have increased the US economy's energy intensity and done so at a high cost to the economy and society[51].

The Burden of Locking-Into Energy-Intensive Systems

Most of the lock-ins mentioned have forced economies onto more energy-intensive pathways than might have occurred in 'socially-optimal' market conditions, and imply that, if circumstances change, consumption patterns will fail to adjust fully for a very long time. Certainly, economies with higher energy intensities are more vulnerable to the impacts of an oil shock[52]. While rising energy prices can stimulate energy efficiency improvements[53,54], these improvements are slow to be adopted[55] and an 'efficiency gap' exists between the most efficient technology and what consumers use[56]. This inability to adjust in the long run, in part due to path dependence, creates a major vulnerability.

This long term lock-in-induced vulnerability to energy price shocks implies market failures and potential costs to the economy and society. For instance, the disruption component of the social cost of oil in 2004 ranged from US$2 to US$8 per additional barrel of oil consumed by the USA and highlights the benefits to the American economy and society from reducing imports of oil[57]. As a result of these types of disruptions, many governments have sought to develop energy security policies.

Energy security policies can work on supply-side or demand-side[58]. In the USA, over the last thirty years, the annual costs of demand-side management projects have been between 0.01% and 0.04% of GDP[59,60]. While there has been some criticism about the estimated benefits of demand side management projects[61,62], they have achieved reductions in vulnerability to rising energy prices[59]. Nonetheless, despite these benefits, demand-side management efforts in the USA peaked in the early 1990s[59], then remained low until 2008[60]. Thus, such policies appear to be at their lowest when energy price hikes occur (such as in 1973, 1979 and 2008) and so tend to be reactive, rather than proactive. Furthermore, these policies rarely address the underlying energy system, particularly related to key infrastructure, and focus more on incremental improvements in the efficiency of energy technologies. Thus, demand-side management offers little real opportunity to place the economy on a less energy-intensive pathway.

Rather than using resources more efficiently, the history of economic development has tended to be based on dealing with resource scarcity by opening-up new frontiers or exploiting new reserves[63]. In turn, supply-side energy security policies aggravate energy-intensive lock-ins. Naturally, some countries have been more aggressive in their supply-side energy policies than others. As an example, the USA's military expenditures to ensure oil supplies from the Persian Gulf has been estimated. In 2004, the price tag for oil consumers, US oil companies and world oil price stability was estimated to be between 0.2% and 0.6% of GDP[64] – and this estimate has now been revised upwards by 300% to 600%[65,66]. However, this example is not an isolated incident – a study[67] looking over more than 60 years and 600 conflicts found that, when a country has oil reserves very near the border, the probability of conflict is three times greater than if neither country has oil (while strategic objectives on the production-side and associated revenue are likely to be a key driver of this finding, it is hard to exclude the influence of national objectives to meet energy demands). In other words, efforts to ensure the security of supply of oil and energy more generally - arguably to counteract the market failures due to path dependence in energy systems - have imposed substantial burdens on economies and societies.

Conclusions

The purpose of this Perspective was to discuss the implications of path dependence in energy systems for economic development, and stimulate further research and debate. The discussion should not discourage governments from seeking to use energy policies to assist objectives of economic development and poverty alleviation. Instead, it offers a reminder to policy-makers that cheap energy is not a 'silver bullet' and can instead have a hidden price tag, especially in the long run.

Economic development needs access to cheap energy services, just as it needs cheap capital and labour. Infrastructure and other large engineering projects, as well as subsidies, can help to provide energy service access at low prices. If well directed, such policies may boost economic development and reduce poverty. Thus, these may be socially desirable, particularly at early phases of economic development.

However, the role of energy services in economic development changes at different income levels. For example, the potential large net benefits of such policies at early phases of industrialization may become net costs on the economy at later phases. So, care should be taken before embarking on large scale projects and policies that leave an economy heavily in debt and offer little growth and development. Furthermore, cheap energy tends to lock economies into energy-intensive patterns (related to technologies, infrastructures, institutions, and behaviour) that are likely to be detrimental to the prosperity of the economy in the long run, increasing the economy's vulnerability to energy price shocks, inflation, trade balance deficits, political pressures from energy companies and environmental pollution.

Once an economy is locked-into an energy system, the government rarely has opportunities to redirect it (see BOX 3). Thus, when an economy is industrialising, and its energy system is being formed (or transformed) and not yet fully locked-in, it is crucial for its long run prosperity that an economy gets on the 'right' path. In addition, this is likely to reduce the costs of meeting global environmental regulation that will, no doubt, eventually be pressed on even the least developed economies. Indeed, the December 2015 agreement in Paris suggests that all economies will eventually need to un-lock themselves from the fossil fuel energy system and, therefore, that industrialising economies may want to avoid locking themselves into this antiquated energy system altogether.

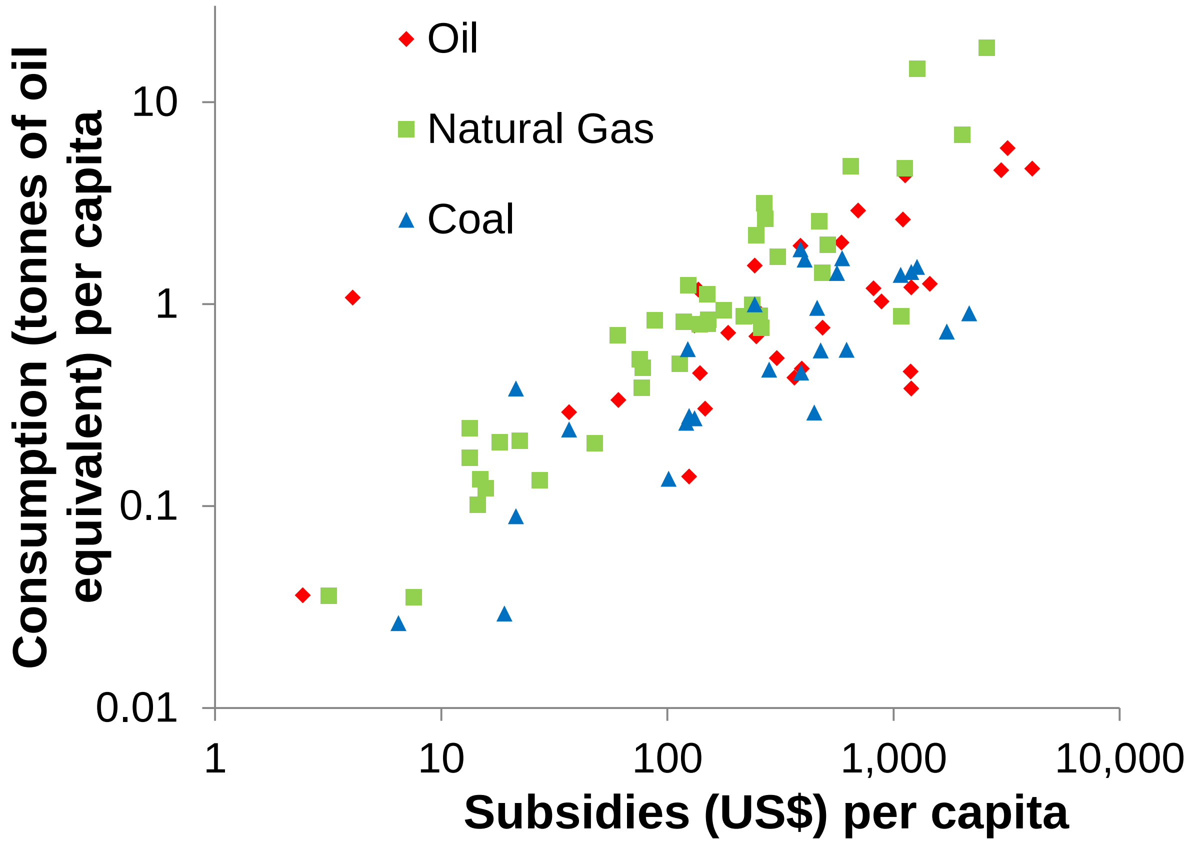

Figure 1. Subsidies and Consumption of fossil fuels in energy-producing economies. The figure plots the relationship between per capita subsidies and per capita consumption of oil (red diamonds), natural gas (green squares) and coal (blue triangles) amongst energy-producing economies in 2013. Data taken from refs 49, 68.

Box 1: The Long Run Effects of Hydroelectric Dams

The state of Kerala in India offers an example of the dangers of energy-intensive path-dependence. Low power costs due to abundant hydropower in the 1930s enabled Kerala to develop quickly (relative to its neighbouring states) by investing in chemical industries. However, the cheap power and the chemical industries locked the economy into a relatively energy-intensive development path, which, by the 1980s, made it unable to develop further, because of the limits of the hydropower supply and the high costs of importing fossil fuels[26]. Thus, the lure of cheap and abundant power can seduce economies into energy-intensive behaviour that eventually makes them vulnerable to energy shortages.

Large scale energy projects like hydroelectric dams also often leave ambivalent long-run legacies for the economy. Dams built for the Tennessee Valley Authority in the USA helped trigger an increase in electricity consumption, though they did little to stimulate regional economic development, as is often believed[27]. In a broader study[69], dams built in India were found to offer some benefits for communities downstream, modestly improving agricultural productivity. However, this was at the expense of increasing poverty in surrounding areas. Thus, the development of these major engineering projects to generate power created large and long-lasting distributional effects that locked certain communities into poverty traps.

Box 2: Path Dependent Energy Technologies

A number of different technologies initially competed in the markets for personal transport[4], electric current[5] and nuclear power[3]. However, in each of these markets, only one technology was likely to dominate in the long run, because of increasing returns to scale resulting from repeated or mass production. An early head-start was crucial for the successful dominance of a particular technology, enabling large production, declining average unit costs and, ultimately, widespread adoption. Thus, small historical events early-on in the competition pushed an energy system towards one particular technology, which in turn increased its likelihood of becoming the dominant technology[1]. For instance, in the late 1940s, the US Navy chose to use light water reactors in its submarines, implying that, in the early 1950s, the US Atomic Energy Commission (under pressure following signs of Soviet nuclear ambitions) selected this technology because it offered the fastest means of generating nuclear power, which key European countries then adopted in the 1960s because of the financial aid they would receive from importing the American technology[3]. Today, light water reactors dominate nuclear power production, despite having been seen as more expensive and less safe than other nuclear power technologies[3]. In this case, and many others, technologies were boosted by their complementarities with other goods, strengthening potential lock-ins[7]. In addition, looking at the automotive industry internationally, one study found that firms tend to direct innovation towards their existing expertise[70]. In other words, lock-ins are not just prevalent amongst chosen technologies, but also within the R&D process, implying that energy systems are likely to be locked-in far longer than originally believed[71].

Box 3: Opportunities to Change Pathway

It is unclear how often opportunities for change (or critical junctures[72]) occur. If there are any patterns, they are likely to vary according to whether they are associated with technological, infrastructural, political or behavioural changes. One concrete example (indirectly related to energy systems, since it does not obviously affect energy consumption) is the techno-institutional lock-in associated with left-hand drive cars (such as in the UK and Japan, but also South-Eastern Africa). In the UK, critical junctures – opportunities to transform the system – would have arguably occurred in 1895 (when the first cars were being built), in 1914 (when the Model-T Ford and its mass production were introduced to the UK, and there were 106,000 cars registered in 1913), perhaps in 1945 after World War II (but by then there were already 2 million cars on the roads), and in 1973 (when the UK joined the European Economic Community and the issue was considered in British Government studies, although the costs (US$5.4 billion in today's money, associated with changing cars and motorway junctions) were deemed too high compared with the benefits; and by which time there were 14 million cars). Thus, critical junctures only occurred roughly every 30 years for this specific and contained techno-institutional problem. For more complex lock-ins, the frequency of critical junctures and opportunities for change could be even less often[72].

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