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Lessons from energy history for climate policy: Technological change, demand and economic development☆

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ABSTRACT

This paper draws lessons from long run trends in energy markets for energy and climate policy. An important lesson is that consumer responses to energy markets change with economic development. The British experience suggests that income elasticities[1] of demand for energy services have tended to follow an inverse-U shape curve. Thus, at low levels of economic development, energy service consumption tends to be quite responsive to per capita income changes; at mid-levels, consumption tends to be very responsive to changes in income per capita; and, at high levels, consumption is less responsive to income changes. The paper also highlights the importance of formulating integrated energy service policies to reduce risks to developing countries of locking-in to carbon intensive infrastructure or behaviour. Without guidance and incentives, rapid economic development is likely to lock consumers into high energy service prices in the long run and bind the economy onto a high energy intensity trajectory with major long run economic and environmental impacts. Thus, effective energy service policies in periods of rapid development, such as in China and India at present, are crucial for the long run prosperity of the economy and their future ability to mitigate carbon dioxide emissions.

1. Introduction

The anthropogenic effects on climate change have their roots in the Industrial Revolution and the associated transformation of the energy system. In particular, it set the global economy on a trajectory of rising levels of energy consumption, with great benefits to mankind, and carbon dioxide emissions, with more worrying consequences. More generally, technological, institutional and behavioural lock-ins imply that energy systems have remained unchanged for long periods of time [4,1,25].

As a result, climate strategies and policies, particularly those related to transforming the energy system, need to look decades or even centuries into the future. However, most climate policies are formulated on the basis of short or medium run perspectives – rarely analysing experiences more than a decade or two in the past.

Probably reflecting the growing need to look back, many notable books and journal articles have been published in the past decade on the history and long run nature of energy markets and their environmental effects (e.g., [17,5,7,73,63,52,43,41,35]). These built on earlier generations of studies related to energy history (including [54,77,10,46,71,15,72,62,57,34]).

The study of the history of energy has offered a number of valuable insights of relevance for today's energy markets and climate policy. For instance, it is important to remember that the evolution of energy technologies has been slow and painfully influenced by the teething problems and idiosyncrasies of the technologies [62]. However, the personalities of entrepreneurs, such as James Watt, Thomas Edison or Nikola Tesla, selling and promoting technologies have also played an important role [63]. Indeed, certain technologies have been selected on the basis of these and other early influences in their history, locking the economy into partic-

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[1] The income elasticity of demand for an energy service indicates the percentage change in the consumption of the energy service for a one percent change in income. For example, an income elasticity of 0.5 (or 1.5) implies that, if income rises by 10%, consumption will increase by 5% (or 15%, respectively). Similarly, the price elasticity indicates the percentage change in the consumption of the energy service for a one percent change in the price of the energy service. That is, a price elasticity of −0.5 (or −1.5) implies that, if prices rise by 10%, consumption will fall by 5% (or 15%, respectively).

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ular combinations of technologies and institutions [74,34,66,67]. Often the successful uptake of specific technologies depended on timing of the introduction and development of technologies, industries and institutions that enabled new energy sources to emerge from niches and become core elements in the regime [76,28].

Furthermore, the diffusion of new energy technologies and sources has had major impacts on the economy and society. They have played a major role in liberating the economy from the limits imposed by land, as characterized by the Industrial Revolution [10,46,72,73,5,43]. There is also evidence that economies were boosted by the improving efficiencies of energy technologies [7]. However, they did not simply reduce the cost of production by providing cheaper energy or energy services to drive the economy, substituting away from relatively expensive labour. Energy transitions also transformed economic activities, enabling more flexible and decentralised production processes [14,38], spurring demographic and social transformations [5] and altering political structures [12].

Historical evidence also supports the expectation that per capita energy consumption and income levels rise together. Traditionally, the energy intensity (i.e., energy consumption-GDP ratio) has been assumed to follow inverse-U shape, peaking with the process of industrialization [77,37,75]. However, the inclusion of biomass and traditional energy sources in the analysis and the study of a broader range of historical experiences indicate that this stylized fact does not always hold, and depends on the characteristics of the economy [30,43]. Nevertheless, there is strong historical evidence for convergence in energy intensity today – both from industrialised economies becoming less energy-intensive and industrializing economies becoming more energy-intensive [13].

In this paper, it would be impossible to summarise further the evidence produced by this vast literature. Instead, here, *the objective of this paper is to provide some specific insights from a comprehensive research programme focussing on the United Kingdom's long run energy trends and developments, and their relevance for energy and climate policy*. The aim of the research programme was to better understand the evolution of the demand for and supply of energy services, which are at the core of energy markets, but are rarely analysed explicitly (see below).

Before continuing, it is important to clarify why the United Kingdom experience is particularly relevant for today. To complete the Industrial Revolution, the United Kingdom needed to undertake a full energy transition (towards fossil fuels). Today, to stabilise the climate and continue to grow in a sustainable way, the global economy needs to undertake a full energy transition (away from fossil fuels). Thus, the British experience in the past and the global economy today are both experiences of leading, rather than following, energy transitions and 'going into the unknown'. Thus, the former may offer insights for the latter.

In the following section, this paper presents trends in the price and consumption of energy services (i.e., heating, power, transport and lighting) over the past three hundred years, discusses estimates of the related trends in income and price elasticities since the Industrial Revolution, and reviews the environmental impacts of energy consumption over this time period. In Section 3, this paper considers the transferability and relevance of past trends and experiences in the United Kingdom for future patterns of behaviour. Section 4 (based on this evidence) offers policy recommendations for climate policy.

It is worth emphasizing that to provide strong lessons and direct policy recommendations while keeping the text concise, this paper has needed to be efficient with its words. Inevitably, this may have led to simplifications. The reader seeking more depth and detail is encouraged to access the referenced publications, and sources for the insights discussed below.

2. Lessons from United Kingdom's energy history

2.1. Insight 1. Energy is consumed in order to meet a demand for energy services

Energy consumers are driven by their demand for energy services (such as space and water heating, transportation, appliance uses and lighting), and the costs associated with these services are crucial for understanding energy consumption patterns. The cost of the energy services generally combines the price of energy and the efficiency of the energy technology used [24].

For example, in the nineteenth century, town gas (derived from coal) was the dominant source of lighting [26]. A town gas lamp from the late 1820s would have generated 130 lumen-hours per kWh; by 1916, the 'Welsbach Mantle' gas lamp produced more than six times more light, 870 lumen-hours per kWh [56]. With this information, and data on gas prices, the price of lighting can be estimated – the price of gas lighting in 1830 was £2,700 (in 2000 money) for one million lumen-hours (equivalent to leaving-on a 100-watt incandescent bulb for 30 days) and, in 1920, it was £40. Today, with LED lighting generating 66,000 lumen-hours per kWh, it costs under £1 for the same amount of illumination. In a similar way, consumption of gas and electricity (or other energy sources) can be combined with the efficiency of the technology to estimate lighting use or the consumption of other energy services.[2]

As shown in this example, an additional advantage of focussing on energy services (rather than energy) is that the demand for energy services remains comparable with the introduction of new energy sources and technologies. Because of improvements in lighting efficiency between the nineteenth and twenty-first centuries, it would be difficult to properly compare long run behaviour without focusing on the service. Similarly, changes in vehicle efficiency pre- and post-1973 imply that the benefits (or utility) to a car user from consuming one litre of petrol has greatly changed over the last forty years, making it difficult to analyse long run demand using direct analysis of car user energy consumption. Instead, focussing on the energy services provided (e.g., the passenger-kilometres or lumen-hours) helps to identify very long run patterns in consumption that would be hidden by focussing only on the changing uses of different energy sources.

2.2. Insight 2. Energy service prices tend to decline in the long run

Evidence indicates that, since the First Industrial Revolution, there has been an acceleration in the tendency of households and firms to find ways of consuming energy more efficiently, producing cheaper energy services [17]. A crucial role was played by knowledge production and its declining cost in driving the transformations in the energy system (stimulated initially by the creation of the patent system in the sixteenth century and the Scientific Revolution in the late sixteenth and seventeenth centuries [53] and of the diffusion of new energy technologies. This was facilitated by the introduction of new energy sources, such as coal/town gas, petroleum products, electricity and natural gas. These improve-

[2] So, while lighting is measured in terms of lumen-hours (where one million lumen-hours is equivalent to leaving-on a 100-watt incandescent bulb for 30 days), passenger transport is measured as passenger-kilometres (km), that is, moving one passenger one km, and freight transport as tonne-km. Residential heating is measured as one tonne of oil equivalent (toe) of effective heating – that is, if a heating system converts one toe (or the calorific equivalent of one toe of firewood, coal, natural gas or electricity) into heating with 100% efficiency, then one toe of 'effective heating' has been consumed. If the heating system is only 10% efficient, as eighteenth century fireplaces were, then the same amount of fuel would only provide one-tenth of one toe of effective heating.