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Economic growth and the transition from traditional to modern energy in Sweden

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A B S T R A C T

We examine the role of substitution from traditional to modern energy carriers and of differential rates of innovation in the use of each of these in economic growth in Sweden from 1850 to 1950. We use a simple growth model with a nested CES production function and exogenous factor-augmenting technological change and carry out a counterfactual simulation based on the econometric results. Even though the rate of technical change was higher for modern energy, innovation in the use of traditional energy carriers contributed more to growth between 1850 and 1890, since the cost share of traditional energy was so much larger than that of modern energy in that period. However, after 1890 we find that modern energy contributed much more to economic growth than traditional energy, but, increasingly, labor-augmenting technological change became the most important single driver of growth.

1. Introduction

How important was the transition from traditional energy carriers, such as firewood and animal feed, to fossil fuels, initially coal, in fuelling the increase in the rate of economic growth known as the Industrial Revolution? Many energy and ecological economists (e.g. Ayres and Warr, 2005, 2009; Cleveland et al., 1984; Hall et al., 2003; Mayumi, 1991) and geographers (e.g. Smil, 1994), as well as many economic historians (e.g. Allen, 2009; Cipolla, 1962; Fernihough and O'Rourke, 2014; Gutberlet, 2012; Kander et al., 2013; Wilkinson, 1973; Wrigley, 1988, 2010) argue that innovations in the use of, and growth in, the quantity of coal played a crucial role in explaining the Industrial Revolution. But some economic historians (e.g. Clark and Jacks, 2007; Kunnas and Myllyntaus, 2009) and economists (e.g. Madsen et al., 2010) argue, instead, that it was not necessary to expand the use of modern energy carriers such as coal and most growth economists (e.g. Galor, 2011) do not assign any special role to energy in economic growth.[1] Our key research questions are: What direct effects on growth did the transition to modern energy and the more efficient use of it have compared to the increased efficiency and expansion in the use of traditional energy carriers? Did these effects vary over the course of the transition? We address these questions using historical data from Sweden for the period 1850–1950.

The pre-industrial energy system was plagued by two limitations that restricted population and per capita income growth (Kander et al., 2013). The first was that of *low power*, as there were no machines to convert heat into motion. This drawback was solved with steam engines and later by internal combustion engines. The second limitation of the pre-industrial energy system was that energy production demanded *vast land areas* for its production, was very labor intensive, and required extensive transportation from geographically dispersed energy sources (Wrigley, 1962). These limitations were overcome

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[1] It is debatable whether coal should be called a "modern" energy carrier given its long history of use in the United Kingdom and China. Coal and wood were used in equal quantities in Britain by the beginning of the 17th Century but after that coal use greatly expanded (Fouquet, 2011). In most other countries, though, coal was only used on a significant scale from the beginning of the 19th Century (Kander et al., 2013).

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during industrialization by coalmines and railways, enabling large amounts of energy to be captured at a single location and be easily transported to urban areas. Still, this pre-industrial society was by no means stationary. Some population growth was enabled by agricultural productivity increases and efficiency improvements in charcoal use in iron production as well as increases in stove efficiency among households (in cold northern Europe). But such improvements were barely able to offset population growth, so energy use per capita hardly grew (Kander et al., 2013). This posed severe limits to income per capita growth in the pre-industrial energy system, and per capita consumption even declined in Europe in the 16th century as a result of colder climate and lower agricultural output. Still, it is plausible that increased efficiency of traditional energy may have played a role in growth, since the use of traditional energy carriers did expand and the efficiency with which they were used increased significantly in the 19th Century (Kander et al., 2013).

Kander et al. (2013) present the first detailed figures on energy consumption for much of Europe reaching back over several centuries and including traditional as well as modern energy carriers. These show that, although economic development has vastly increased energy use, it has not been a story of smoothly increasing energy consumption. The traditional energy economy of medieval and early modern Europe was marked by stable or falling per capita energy consumption. The Industrial Revolution saw a rapid expansion in the use of coal and technologies including iron smelting and steam engines that exploited it. Kander et al. (2013) demonstrates that the reduced costs of producing iron with coke were essential to cheap machinery production and capital-deepening industrialization and that continued innovation that improved energy efficiency and reductions in the cost of transporting coal with steam-powered ships and trains, eventually made coal-using technologies profitable in other countries too. Berg (1978) similarly argues that innovation that allowed coal to be used in novel ways drove the shift to coal in the United States far more than any scarcity of firewood.

However, the analysis of Kander et al. (2013) is limited to verbal discussion of tables and graphs of the time series (firewood, coal, oil etc.) and ratios of the time series, such as energy intensity, which they decompose into structural and technical change. In this paper, we aim to advance the argument one step further by for the first time quantitatively modeling the role of both traditional and modern energy in economic growth during the Industrial Revolution.

We use Sweden as a case study partly because of good data availability. Though long-run historical energy use data are now available for several countries in Europe and North America (Gales et al., 2007; Henriques, 2011; Kander, 2002; Kander et al., 2013; Malanima, 2006; Warde, 2007), national price series are only available for Britain (Clark, 2004; Fouquet, 2011) and Sweden (Kander, 2002). Energy prices varied greatly depending on whether a location was close to coal and wood resources or not and so the way that the individual price series are weighted is critical. The Swedish price series seems to be the most consistent long-run national energy price series.[2] Also, the transition to coal took place very early in England and data for that period are naturally scarcer and less certain. On the other hand, there are fairly reliable GDP figures for Sweden starting in 1800 (Krantz and Schön, 2007). There is also reason to expect a clearer connection between industrialization and the transition to modern energy carriers in Sweden than in England. In England, coal was already used on a large scale long before the introduction of steam engines and industrialization, simply to replace firewood for heating purposes (Warde, 2007). In Sweden, which has only a very little domestic coal located in the western part of Scania, coal use had a much clearer connection to the Industrial Revolution.

We aim at a more formal quantification of the ideas of many economic historians that the transition to modern energy was crucial for driving economic growth during the Industrial Revolution. In a previous paper (Stern and Kander, 2012), we extended a conventional Solow (1956) growth model to include energy and biased technological change, but we did not distinguish between modern and traditional energy. With this model, we showed that the expansion of energy use, increases in energy quality,[3] and energy-augmenting technological change explained much of the growth in Sweden up till 1950. Thereafter, labor-augmenting technological change became dominant in explaining economic growth. This previous result provides one rationale for restricting our analysis to the period 1850–1950. Another reason is that the transition to coal in Sweden took place from 1850 to 1950.[4] Oil use was quite low until the very end of the period after which it surged. Extending the period of analysis from the more conventional economic history endpoint of 1913 up until 1950 has another advantage: the extended period contains two World Wars, when coal imports were severely restricted in Sweden and the government initiated attempts to replace these lost imports with firewood and hydropower (Kaijser and Kander, 2013). These World Wars should provide much information on substitution possibilities.

An additional contribution of our paper is an estimate of the elasticity of substitution between these traditional and modern energy carriers. Though there is a large literature on interfuel elasticities of substitution between modern fuels – coal, oil, natural gas, and electricity (Stern, 2012) – we only know of one study – Jones (2014) – that estimates cross-price elasticities between biomass and other fuels. Our paper also contributes to this literature, though results should be interpreted with some caution because of the way that the firewood consumption series has been constructed.

The next section of the paper describes our model. This is an extension of Stern and Kander (2012) to allow for multiple energy inputs and to differentiate between technological change that improves the efficiency of the use of modern and traditional energy carriers at different rates. The third section describes the sources of our Swedish data set. This is followed in the fourth section by a discussion of the data in the context of Swedish economic history. In the fifth section of the paper, we present the econometric results including estimates of the rates of factor-augmenting technological change and the interfuel and interfactor (between the capital-labor and energy aggregates) elasticities of substitution. We then use these results to carry out a series of counterfactual simulations to determine the importance of the various factors in economic growth over time. Our key finding is that the contribution of modern energy-augmenting technological change was small in comparison to traditional-fuel-augmenting technological change between 1850 and 1890. This is because a small sector that is highly innovative may not affect overall GDP growth very much, a fact that has caused much discussion in economic history of the appropriateness of the term “Industrial Revolution” referring to a period in time when the modern sectors were still very small and could not logically have much impact on overall GDP growth (Harley and Crafts, 2000; Temin, 1997). Instead improvements in the efficiency of the use of traditional energy contributed significantly to growth from 1850 to 1890. But this

[2] Clark provides coal price series for England, London, the North of England, the rest of the country, and at the pithead. (http://www.iisg.nl/hpw/data.php#united) up till 1869. However, the sources cited (Clark, 2004, 2005, 2007) do not explain how the series were constructed or how local data were weighted. Fouquet (2011) provides series of coal and wood prices deflated by the consumer price index. For the period prior to 1866, he used Clark's series and between 1866 and 1966 he used price series for London and export prices provided by Mitchell (1988). By contrast, the Swedish price series is nationally weighted and uniformly uses retail prices. Both Clark (2004) and Fouquet (2011) note that their English series is biased towards London, which introduces anomalous behavior (Clark, 2004, 52; Fouquet, 2011, 8).

[3] Energy carriers vary in quality, which reflects their productivity, flexibility, and other properties (Stern, 2010). Generally, primary electricity is seen as the highest quality energy source and coal, wood, and other combustible biomass as the lowest, with oil, gas, and animal power at an intermediate level.

[4] In 1850, coal constituted about 2% of energy use by heat content in Sweden, which is similar to the current share of “new renewables” in global primary energy use today. By 1870, the share of coal was 10%. The growth rate of per capita coal use was 5.8% per annum in the two decades prior to 1850 and 7.9% per annum in the two decades following 1850 (Table 2).