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ANALYSIS

Electrification and energy productivity

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ABSTRACT

Energy productivity is crucial for sustainable development. We use cointegration analyses to investigate the effect of electricity on energy productivity in Swedish industry from 1930 to 1990. Electricity augmented energy productivity in those industrial branches that used electricity for multiple purposes. This productivity effect goes beyond "book-keeping effects," i. e. it is not only the result of electricity being produced in one sector (taking the energy transformation losses) and consumed in another (receiving the benefits).

1. Introduction

Productivity, i. e. producing more from a certain amount of inputs, is a driving force for economic development. It involves productivity increases in relation to labour, but also in relation to capital and other inputs such as energy and material. These days, increases in energy productivity are particularly relevant for cutting down greenhouse gas emissions. One way of increasing energy productivity is to increase the share of electricity in the energy consumption basket. This is because electricity has a particular role in changing production processes in industry, by enabling new organization of workers and machines.

Historical investigations of the relation between electricity and productivity in the US economy have primarily been focused on the breakthrough period of the electrical motor from the 1890s to the 1920s. Schurr and Netschert (1978) have noticed that there was not only a general productivity surge in the 1920s, but also a steep increase in energy productivity, which they conjecture was related to the electrification of industry. Devine (1983) connected general productivity growth with energy productivity growth. He explicitly explained the productivity effects that arose from the electrification of industry, when steam and water powered prime movers were replaced by electric motors that first drove groups of machines and later individual machines. Not only did this mean that energy was saved, because of reduced losses in the transmission of power within the industrial factories; it also improved working conditions and control of machines and enabled the gradual expansion of plants. Together, this improved the productivity of labour and capital. It was not just the electric motor that had these productivity effects, but also electric light which improved the working conditions. The productivity effects were further emphasized by David (1990) in a discussion of "productivity paradoxes," when he regarded the productivity increase in the first decades of the 20th century as a delayed effect of the introduction of the electric dynamo in the 1880s.

Ayres et al. (2005) investigate the efficiency of US electricity usage since 1900, and find that the efficiency in electricity use has not increased. In every individual electricity use (for light, for motion, for high temperature heating, for low temperature heating) thermal efficiency has increased substantially, but the composition of electricity use has changed in direction of a larger share of the electricity being used for the least efficient use (low temperature heating), so the overall thermal efficiency has not improved. While Ayres et al. look at the efficiency in transforming electricity to energy services, we investigate energy productivity in economic terms (the value added that electricity contributes to creating), see Fig. 1.

Moser and Nicholas (2004) question that the surge in US productivity growth in the 1920s is attributed to electrification. Using patent statistics, they find that electricity does not stand out as exceptional in comparison with other technology fields. They use a sample of American patents in the 1920s and the citations that these patents received much later: in the period between 1976 and 2002. They find that although electricity patents were broader in scope and more original on the date of grant, they had lower generality scores than other sectors (due to fewer forward citations per patent and a lower range of different industries that cite the patents) and a shorter impact period (the mean time between the grant date of a patent and the date of all its forward citations). This may well be true, but the question is if patent statistics is the appropriate means for evaluating

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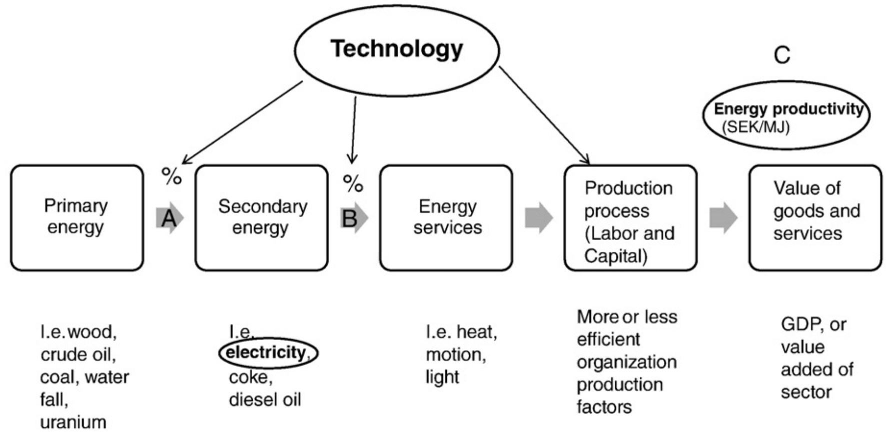

Fig. 1. A conceptual model of the production process from an energy perspective.

productivity effects. We think that Moser and Nicholas (2004) play down the role of electricity inventions, by only counting technical inventions within the electricity producing sector as "real" electricity inventions, and neglect the inventions within electricity-using sectors. However, in a discussion of electricity from an economic growth perspective it is absolutely essential to look at the productivity effects of *using* electricity. A second problem with their analysis is that patent citations are unsuitable for testing whether electricity is a widely adopted technology or not. This is simply because when something is general enough it becomes common knowledge, so there are no longer any citation requirements for subsequent patents. This means that all machines that use electricity as a power source between 1976 and 2002, or all lighting equipment, or heating by means of electricity do not cite electricity patents from the 1880s. Neither do all micro-electronic patents of the 1970s cite the basic electricity patent, although integrated circuits make use of low current electricity. Electricity is so deeply embedded in our society that hardly anything functions without it, exactly because it is a general purpose technology, and to paraphrase Solow (1987): "We find electricity everywhere but in the patent statistics."

This paper contributes to long-term studies of productivity effects from electrification. We use Swedish industry as our case, not only because Swedish industrial statistics at the sub-sector level are detailed back to the breakthrough period of the electrical motor, but also because electricity has been very influential in Swedish industry, which is still today very electricity intense compared to other countries. Sweden went for electricity early on in its industrial development, and thus it is a highly relevant case study of productivity impacts from electricity. The lack of domestic fossil fuels, but abundant access to waterfalls, made electricity a cheap and attractive choice. Electrification was central in the decisive acceleration of Swedish industrialization from the 1890s onwards. The development of electrical utilities and electrical engineering industries was stimulated by the demand from energy-intensive industries. The Swedish state actively promoted the adoption and diffusion of electricity, establishing a national grid, connecting the sites of electricity generation in the far North with the consumption locations in the South, in the 1930s. The inter-relationship of electricity, productivity and structural transformation of industry was previously studied by Schön (1990, 1991, 2000). He showed that electrification was part of a broader structural transformation of industry that followed a specific pattern. Leaps in electricity use and in the share of electricity were taken in three periods of roughly 15–20 years, namely 1900–1920, 1940–1960 and 1975–1990. These periods coincided with technological breakthroughs in electricity equipment and utilities as well as with disruptions in the supply of fuels. Furthermore, electrification was part of a technological upgrading and the share of human capital increased more decisively in sub-branches that electrified (a case of technology/skill complementarity). In that sense, Schön identified electricity as a force behind long-term labour productivity growth in Sweden. The productivity effects were delayed, however, until the industrial organization was rationalized and the share of electricity stabilized. Productivity growth increased in the 1920s, 1960s and 1990s. Hence, the productivity paradox effect in relation to electricity repeated itself.

This article addresses a somewhat different question than previous studies by Schön. Instead of putting the productivity effects into a cyclical pattern and studying delayed effects of 15–20 years we here investigate more or less concomitant effects (with only a few years lag). We further investigate the impact from electrification directly on energy productivity (value added/energy quantities) and not on labour productivity. Energy productivity is highly relevant today in its own right, with the threats of global warming. Further, one can assume that effects on energy productivity will have an effect also on labour productivity, even though this may come with a more pronounced time lag, as suggested by previous studies by Schön and Devine.

We use the time-series method of cointegration to investigate the impact of electrification on energy productivity in some broad Swedish industrial sectors and we find a strong impact of electrification on energy productivity in the machinery and chemicals sectors. These sectors use electricity for multiple purposes and have a larger potential for receiving dynamic productivity effects from the reorganization of production processes. In a second step we sharpen the test to rule out the probability that all these energy productivity gains from electrification are due to electricity being a more refined energy source than oil or coal. When one switches from fuels to electricity within a factory, electricity can be used with greater thermal efficiency than fuels, so energy services are larger. Still the inefficiencies do not disappear from the total national economy; they just simply take place somewhere else, in this case in the electricity generation in the power plant and line transmission to the factory.

We label the gains in a user industry from switching from coal or oil to electricity as "book-keeping effects," since energy losses in electricity production are borne by the electricity-generating sector and not by the electricity-using industry. Thus we check whether we can make certain that the energy productivity effects we find are still there, even with this considered, really augmenting energy productivity, as suggested by earlier analyses like Devine (1983). Last, but not least, we check the direction of the short-term causal relation between electricity and energy productivity.

2. Theory and conceptualization

Innovations in energy technologies are principal drivers of economic growth. From the steam engines, to the internal combustion engine, the electric generator and electric motor, the possibility of