Directed Technical Change and Energy Intensity Dynamics: Structural Change vs. Energy Efficiency

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Executive summary

The relationship of energy use and economic activity has been a recurring theme in the political and academic debate, particularly since the energy crisis in the 1970s. For the period after the energy crisis, in particular after the mid-1990s, there is strong evidence for substantial reductions in energy intensity in the majority of developed economies. In order to investigate the drivers of energy intensity developments across countries, numerous studies have used decomposition analyses to disaggregate energy intensity into its components. Most studies decompose energy intensity into a structural effect and an efficiency effect (also referred to as technology or (sectoral) intensity effect). The latter describes energy efficiency improvements within sectors, i.e. reductions in sectoral energy intensities due to e.g. substitution of energy by other factors or energy-saving technological progress. The structural effect refers to structural adjustments towards sectors with low energy intensities. Overall, the data analyses on energy intensities show the following stylised trends:

(i) while energy intensities were constant or increasing in the majority of economies until the early 1970s, they systematically decreased since the energy crisis across economies;

(ii) the contributions of energy intensity reductions within industries, e.g., through technological progress (efficiency effect) or structural change towards less energy-intensive economic activities (structural effect) to energy intensity reduction differ substantially across countries.

In contrast to the extensive data analyses on energy intensity developments, there is a lack of theoretical approaches to analyse the underlying mechanisms of the trends described above. Recent studies highlight the exploration of the determinants of these developments, including the role of technological change, as directions of future research. Our paper aims to fill this gap by providing a, to our knowledge, first theoretical analysis of energy intensity dynamics. The main aim of this paper is to analyse how endogenous technical change and energy price affect the direction and magnitude of the structural and the efficiency effect.

For our theoretical analysis, we use a stylised two-sector Directed Technical Change model with a labour-intensive and an energy-intensive sector, such that we can differentiate between structural adjustments in the economy and within-sector energy efficiency improvements. We first determine how energy price growth and the relative productivity of the labour- and the energy-intensive sector affect the direction of technical change. After decomposing overall

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energy intensity into efficiency effect and structural effect, we investigate how the direction and magnitude of both effects is affected by technical change and energy price growth. Finally, we calibrate the model to empirical data for 26 OECD countries covering the period 1995-2007 to illustrate our results and to cross-check our findings with empirical decomposition studies.

Our model results provide insights on the impacts of energy prices and technical change on the development of energy intensity and, in particular, the relative importance of structural adjustments between sectors and energy efficiency improvements within sectors. We find that the efficiency effect dominates the evolution of energy intensity in economies, when research is directed to the energy-intensive sector. This efficiency effect is driven by technical change in the energy-intensive sector as well as factor substitution induced by energy price growth, which is in line with empirical findings. When research is directed to the labour-intensive sector, the structural effect is the main driver of energy intensity dynamics. Consistent with empirical evidence, our model predicts a negative effect of energy price growth on economy-wide energy intensity, irrespective of the direction of research. Finally, we show that energy price shocks might induce a permanent redirection of innovation activities.

In our simulation based on empirical data, we illustrate the main results of our theoretical model, i.e. how differences in sectoral productivities and different energy prices between countries affect energy intensity dynamics. In 11 out of the 26 OECD countries, the developments of energy intensity are dominated by the efficiency effect. This can be seen, e.g., for Austria and Germany. In the remainder of the economies, as France or the United States, the structural effect is the main driver of energy intensity dynamics. In spite of our very stylised model, the results are largely consistent with empirical studies.

Our main contribution to the literature is a first attempt to theoretically analyse the determinants of heterogeneous energy intensity trends based on a dynamic model with endogenous technical change. We offer theoretical mechanisms to understand why structural adjustments drive energy intensity reductions in certain countries, whereas they are dominated by within-sector efficiency improvements in others. Understanding these underlying drivers offers insights for policies that aim to reduce energy intensities. Energy taxes, e.g., are capable to induce energy savings, as the end-user price of energy and negatively affect energy intensity according to our model. However, price increases mainly induce energy intensity reductions within the energy-intensive sector. A redirection of research to labour-intensive sectors would require very high price increases. As our approach is a first step to theoretically analyse underlying drivers of energy intensity dynamics, extensions or alternative theoretical modelling strategies seem a fruitful direction of further research. The extensive empirical literature has taught us a great deal about energy intensity developments and its decomposition, whereas the underlying determinants are still largely unexplored.

Keywords Directed technical change; Energy efficiency; Energy intensity; Structural change.

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