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Assessing the technological responsibility of productive structures in electricity consumption

Vicent Alcántara [a], Miguel-Angel Tarancón [b], Pablo del Río [c,*]

[a] Universidad Autónoma de Barcelona, Barcelona, Spain
[b] Universidad de Castilla-La Mancha, Ciudad Real, Spain
[c] Institute for Public Policies and Goods (IPP), Consejo Superior de Investigaciones Científicas, C/Albasanz 26-28, 28037 Madrid, Spain

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ABSTRACT

A methodology is developed which allows us to measure the responsibility of the productive structure of an economic system with respect to the consumption and generation of electricity within an input–output framework. We propose a technical indicator of technology responsibility in electricity consumption based on the assessment of technical coefficients. Technological responsibility refers to the capacity of a sector or economic transaction between sectors to induce electricity consumption regardless of the final demand vector. Sectors with a high technological responsibility are those whose technologies use inputs which either directly or indirectly require much electricity independently of the composition of the final demand in the economy. This methodology is applied to the productive sectors of the Spanish economy. It is found out that a few transactions between sectors are highly technologically responsible regarding electricity consumption. The results show that, although the service sectors are the ones with the greatest share in electricity consumption, the industrial sectors (particularly, the extractive, heavy and energy industries), the electricity generation sector and construction are the ones with the greatest technological responsibility, i.e., they have technology mixes with a large propensity to consume electricity, propagating to the other sectors. The sectors with the highest technological responsibility are clustered around three broad sectors: energy, metal manufacturing and transport.

1. Introduction

Electricity is a crucial product in our modern daily life. However, it also has negative side-effects and, thus, reductions of electricity demand have generally been defended on environmental and energy security grounds. On the one hand, fossil-fuel fired electricity generation leads to significant emissions of local and global pollutants. Lower electricity demand reduces the emissions of greenhouse gases (GHG) to the atmosphere. In 2008, electricity generation accounted for 40.7% of CO_2 emissions in the world and 36.1% in the EU (IEA, 2010). Growing concerns about the effects of GHG emissions on climate change have placed pressure on the world's leading economies to improve the efficiency of energy use. In turn, dependence on foreign fossil-fuel energy sources has also been used as an argument to reduce electricity demand through energy-efficiency measures.[1] Finally, reducing electricity demand helps to reduce expensive electricity infrastructure in peak periods.

Realising energy-efficiency potentials requires the introduction of good energy-efficiency policies (Harmelink et al., 2008). In turn, an analysis of the anatomy of electricity consumption within an economy is crucial in order to identify policies which may eventually influence such consumption. The aim of this paper is to analyse the technological responsibility of different sectors with respect to electricity consumption. “Responsibility” is understood, in this context, as “impact” on electricity consumption/production. Sectors with a high technological responsibility are those whose technologies use inputs which either

* Corresponding author. Tel.: +34 916022560.
E-mail addresses: vicent.alcantara@uab.cat (V. Alcántara), miguelangel.tarancon@uclm.es (M.-A. Tarancón), pablo.delrio@csic.es (P. del Río).

[1] Although the electricity generation mix is relatively diversified in Spain, with 18% coming from non-hydro renewables, 14% from hydro, 8.5% from coal, 32% from gas and 20% from nuclear in 2010, this country is not endowed with significant fossil fuel reserves. Thus, it has to import most of these resources as inputs in electricity production, which come from countries with geo-strategic risks. For example, the natural gas imported comes from Algeria (29%), Nigeria (21%), Qatar (15%), Trinidad and Tobago (8%) and Egypt (8%). 40% of the coal used by thermal plants is domestic and 60% is imported (Ministry of Industry, Tourism and Trade, 2011).

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directly or indirectly require much electricity independently of the composition of final demand in the economy.

For this task, we use an input–output framework, which allows us to analyse how the direct and indirect electricity consumption of several productive sectors spread throughout the economic system. This allows us to assess how changes in the electricity efficiency of given sectors influence the degree of electricity efficiency of other sectors, depending on their mutual linkages. By electricity efficiency we refer to efficiency in the use of electricity, i.e., the overall efficiency in electricity consumption of the production system.

Within the realm of the analysis of the relationships between the productive system and energy consumption with an input–output methodology we can distinguish two broad approaches, based on whether changes in flow variables or structural (or technological) elements of the production system are analysed. When analysing the energy efficiency linked to sectoral technologies, the second broad approach should be used since a change in efficiency involves a previous change in the sectoral technologies. Within this approach, an ex-post and an ex-ante perspective can be distinguished. The ex-post perspective is linked to techniques based on structural decomposition analysis (SDA). The ex-ante perspective is linked to the location of important technical coefficients through the sensitivity analysis of those coefficients, allowing us to identify the "skeleton" or structure of productive relationships which have a greater relevance from the energy point of view.

The Leontief quantity model allows the identification of those sectors/actors whose changes in final demand lead to the greatest variations in electricity production (for a given technology). However, it is unable to identify the degree of technological responsibility of sectors. Although ultimately electricity demand (both final and intermediate demand) will determine the level of national emissions, reducing electricity intensity in some "responsible" sectors is one means of reducing the intermediate demand portion of that equation.

Structural decomposition analyses are able to measure the effect of technological changes on electricity production. They require information which refers to two input–output tables, which complicates matters because the effect of differences in relative prices should be accounted for and mixed effects have to be distributed in a rather arbitrary manner between the final demand effect and the technological responsibility effect (Dietzenbacher and Los, 1998). A complementary method to assess and characterise the technological responsibility of a sector with respect to electricity demand is to analyse how overall electricity consumption reacts to variations in the technological mix of such a sector, i.e., to assess the sensitivity of electricity consumption with respect to changes in the technology of the analysed sector. This is the approach followed in this paper.

When analysing the role that each productive sector plays in electricity consumption, it is worth using the concept of "technological responsibility" rather than merely focusing on "importance". The difference between both concepts in terms of electricity efficiency is straightforward. "Importance" includes the final demand vector affecting electricity consumption in the whole economic system and, thus, this concept depends on the economic situation. Structurally responsible sectors are those whose products are much demanded by other sectors, leading to a high level of electricity consumption/production. In contrast, "technological responsibility" pays attention to the influence that a sector's technology has on electricity demand, independently of the current final demand vector. Thus, sectors with a high technological responsibility are those whose technologies use inputs which either directly or indirectly require much electricity independently of the composition of the final demand in the economy (Tarancón and del Río, 2012). This concept is relevant when considering that long-term trends of increasing consumption of electricity (both directly or indirectly) are expected, and therefore the technical aspect of electricity consumption becomes very important.

In order to build an indicator of technological responsibility, we assess the capacity of technical coefficients to change the level of electricity efficiency which is associated to a long-term equilibrium situation, the so-called "uniform growth rate (UGR) of the economy", rather than assessing those technical coefficients with respect to a given demand vector. The UGR is the inverse of the dominant eigenvalue associated to the matrix of technical coefficients within an input–output framework (see Section 3). We calculate a matrix of sensitivities of the level of electricity efficiency with respect to the variation of the technical coefficients. This calculation, which provides a picture of the technological structure of each sector, is based on the properties of "similar matrices".

Therefore, the paper provides the following methodological contributions:

- It proposes the concept of technological responsibility with respect to the efficiency of electricity consumption, in contrast to the concept of importance.
- It quantifies the technological responsibility by using the UGR concept and by developing a methodology based on two properties of the matrices of input–output coefficients: the dominant eigenvalue of matrices and the similar matrices. The responsibility of a structural change in a sector, in a situation of a long-run equilibrium and independently of the final demand flows at a given moment, can then be assessed.

The concept of technological responsibility, which is quantified by the methodology proposed in this paper, allows us to grasp the implications of technological rigidity (existing in production processes) on electricity consumption. It suggests that publicly promoting electricity efficiency in industry is a necessarily limited endeavour, given the input–output relationships which underlie the production process and which are difficult to change for electricity efficiency reasons. Policy-makers are well advised to take this technological rigidity into account when designing policies aimed at increasing electricity efficiency. We apply this methodology to the Spanish case by using the input–output table in 2005.

Accordingly, the paper is structured as follows. The following section provides the analytical framework and discusses previous contributions in the literature. Section 3 develops the methodology. Section 4 illustrates the application of the methodology with an analysis of the Spanish case. Section 5 concludes.

2. Analytical framework: electricity consumption and intersectoral relationships

This section develops the analytical basis of our proposal by specifying the input–output relationships that will be taken into account.

Let's assume that the productive system has n sectors. Thus, if c represents the vector $(n \times 1)$ of total electricity consumption by the sectors in physical units and x is the vector $(n \times 1)$ of sectoral output in monetary terms, the following relationship can then be established:

$$c = \hat{e}x \tag{1}$$

where $\hat{e}$ is the diagonal matrix which includes the coefficients of energy valuation. The latter represent the quantity of electricity consumed in physical units per monetary unit.

Let X be the matrix $(n \times n)$ of intermediate consumptions, with the element x_{ij} representing the purchases by sector j of goods produced by sector i. Let y be final sectoral demand vector $(n \times 1)$. The production vector x can then be expressed as follows:

$$x = Xu + y \tag{2}$$

where u is a unitary vector $(n \times 1)$.

From Eq. (2), we can define the $(n \times n)$ matrix of technical coefficients A. The typical element of this matrix is $a_{ij} = \frac{x_{ij}}{x_j}$, which represents