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Measuring non-residential electric energy efficiency in the Portuguese economy

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Abstract

This paper focuses on efficiency of electricity consumption in the Portuguese productive sector using stochastic frontier analysis. It accounts for the rebound effect – the extent to which energy efficiency savings are re-spent on energy consumption – since this can significantly alter the interpretation of the data on measured energy efficiency. Conventional stochastic frontier analysis does not allow for autoregressive errors in estimation and the measured efficiency scores can be seriously biased in the presence of error terms that are not identically and independently distributed. Therefore we allow for autoregressive errors by extending the generalized least squares estimator to include an error components model of stochastic frontier analysis.

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Keywords: energy efficiency, stochastic frontier analysis, rebound effect

1. Introduction

In this paper we investigate the energy efficiency of non-residential electrical energy consumption in Portugal. Clearly the topic is in everyone's mind as the world experiences climate change, but we will discover that there are many confusions about what is meant by energy efficiency. The most widely used metric is the energy intensity of GDP, or in our context the ratio of non-residential electrical energy consumption (in kWh) to GDP at constant prices (in thousands of Euros). Amongst energy economists this metric has been widely criticised, and it is appropriate to ask whether in the field of efficiency and productivity analysis there is a more intelligent approach to the measurement of energy efficiency.

We will show how efficiency and productivity analysis has been used to develop a meaningful economic approach to measuring energy efficiency. This can be applied in both data envelopment analysis and

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stochastic frontier analysis, but in this paper we concentrate on the stochastic frontier analysis approach. Nevertheless, it soon becomes clear that the simple concept of energy efficiency – at least as it is represented in popular discussion – fails to take account of a major contribution of economic analysis known as the rebound effect. This rebound effect is derived from the fact that technological advances in energy efficiency of appliance and capital equipment use that reduce the amount of energy input needed to achieve a particular level of economic activity are equivalent to a reduction in the relative cost of energy. Such a reduction in the relative cost of energy has a substitution and an output effect on demand which can lead to an offsetting increase in energy demand as the benefits of lower costs are re-spent on energy intensive goods and services. This is the rebound effect.

There are particular issues that arise in measuring energy efficiency in individual countries. In this paper we consider the non-residential electricity consumption in a time series sample for the economy of Portugal from 1970 to 2014, a forty-five year period. The application of the standard stochastic frontier analysis model to a pure time series sample for a single country is not straightforward. There may be problems of autocorrelation and heteroscedasticity in the residuals which make their usual interpretation as components of idiosyncratic error and inefficiency problematic. In particular, both autocorrelation and heteroscedasticity lead to biases in measured inefficiency in the stochastic frontier analysis models. It is necessary therefore to develop efficient and consistent estimators of the usual error component parameters to measure inefficiency in a time-series context. We will suggest two different approaches to this modelling challenge.

In summary therefore, there are three major problems that confront researchers when measuring energy efficiency: a) the economic definition of the concept in the context of efficiency and productivity analysis; b) the allowance for the rebound effect which may cause efficiency savings to disappear immediately following technological change; c) the design of econometric estimators with attractive statistical properties.
Section 2 of the paper discusses the first issue: the definition of energy efficiency and section 3 analyses the relationship with the rebound effect. In section 4 we derive a model for estimation and examine the choice of estimators. Section 5 explains the data sample, sections 6 and 7 present the empirical results and discuss their interpretation. Section 8 concludes the paper.

2. Modelling energy efficiency

In this paper we examine energy efficiency in the non-residential electricity consumption, i.e. agriculture, industrial and services sector, in Portugal over the period 1970-2014. Begin with the standard energy intensity relationship:

$$energy\ intensity = E/Y \qquad (1)$$

Here E is energy consumption (or expenditure in real terms) and Y is the level of economic activity in the same sector, e.g. Y = GDP at the national level.
This is the standard measure of energy efficiency adopted widely in policy discussions and it has analogies with the simple crude measures of labour productivity that ignore other inputs, industrial characteristics and prices. In Figure 1, we illustrate this measure of electric energy intensity in Portugal for all productive activities and their sectoral composition. Electrical energy intensity has shown a steady increase over the period, and a superficial conclusion would be that electrical energy efficiency has decreased despite this being a period of increasing technological change.

However, as shown by Filippini and Hunt [1], [2] measuring energy efficiency through energy intensity is too simple because other variables and random errors impact on the measured intensity. They argued that energy demand can be modelled broadly as: