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Estimating the potential for electricity savings in households☆

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ABSTRACT

Improving efficiency in the use of energy is an important goal for many nations since end-use energy efficiency can help to reduce CO_2 emissions. Furthermore, since the residential sector in industrialised countries requires around one third of the end-use electricity, it is important for policy makers to estimate the scope for electricity saving in households to reduce electricity consumption by using appropriate steering mechanisms. We estimate the level of technical efficiency in the use of electricity using data from a Swiss household survey. We find an average inefficiency in electricity use by Swiss households of around 20 to 25%. Bottom-up economic-engineering models estimate the potential in Switzerland to be around 15%. In this paper we use a sub-vector input distance frontier function based on economic foundations. Our estimates lie at the upper end of the electricity saving potential estimated by the afore-mentioned economic-engineering approach.

1. Introduction

A third of the total end-use electricity consumption in OECD countries originates from households (IEA, 2015). Therefore, the residential sector could be an important driver of energy efficiency saving. The actual potential of electricity saving in the residential sector is an important question. This is relevant for most industrialised nations as end-use energy conservation can significantly help to reduce CO_2 emissions (IEA, 2009).

McKinsey & Company (2009) have estimated the potential for energy savings for all end-uses, except transport, in the US. They apply an economic-engineering approach based on bottom-up models. As a foundation they use the National Energy Modeling System (NEMS) maintained by the Energy Information Administration (EIA) to produce reports for the Annual Energy Outlook. In the residential sector they identify different typical household types and calculate the potential savings for each energy-saving measure. They predict electricity saving in 2020 in the residential sector to be 25%.

Prognos (2011) estimates the potential for energy saving in Switzerland similar to McKinsey & Company (2009). They find that the electricity consumption for households can be reduced by almost 15% by 2035 compared to the reference scenario. In such economic-engineering models the researcher has to make assumptions on the future technology. This paper, on the other hand, follows a top-down approach using stochastic frontier analysis based on microeconomic production theory to measure the level of technical efficiency in the use of electricity in Swiss households. This approach uses a relative technology benchmark, which is given through the sample. As some households in the sample have newer appliances and technologies at home, we measure the potential of electricity saving using today's technology. In this way, we can estimate this potential independent of assumptions on future technologies.

It is important to note that energy demand is derived from the demand for energy services within the framework of household production theory. We assume that households purchase inputs such as energy and capital (household appliances) and combine them to produce outputs which are the desired energy services such as cooked food, washed clothes or hot water (Flaig, 1990; Muth, 1966). We can, therefore, attribute a production function to this process.

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Following the neoclassical production framework (Debreu, 1951; Farrell, 1957), we assume that households minimise the amount of inputs used in the production of a given amount of output and choose the input combination which minimises production costs. However, in practice, we observe that households may be producing energy services without minimising the use of all inputs or at least one of the inputs thereby leading to possible inefficiency in the use of electricity. Since producing energy services can be considered to be the result of a production process we can measure how efficiently it is produced, referred to as the productive efficiency.

Productive efficiency in a microeconomics framework is traditionally measured in a radial way, meaning that the focus is on the efficiency of all inputs used in the production process. However, in this paper, we are only interested in the efficiency in the use of one of the inputs, namely electricity. In this context the concept of input-specific efficiency in the use of an input introduced by Kopp (1981) is useful. As we discuss later in more detail, there are several approaches within the production theory to measure input-specific efficiency. We follow an approach, similar to Zhou et al. (2012b), that estimates a sub-vector input distance function[1] using stochastic frontier analysis (SFA).

This paper has one major contribution to the existing literature. While the stochastic frontier approach has been used with aggregated energy data using either an energy input demand frontier function (e.g. Filippini and Hunt, 2012; Filippini et al., 2014) or a sub-vector distance function (Zhou et al., 2012b),[2] we use disaggregated data since residential consumers are typically very heterogeneous and it can add more detail to the knowledge of consumer response. Weyman-Jones et al. (2015) are one of the first to estimate energy efficiency using SFA with disaggregated household survey data. They estimate an energy input demand frontier function originally proposed by Filippini and Hunt (2011) using a cross-sectional household dataset from a survey in Portugal. However, the model used by Weyman-Jones et al. (2015) is relatively simple with only a few explanatory variables. Alberini and Filippini (2015) use a similar energy demand frontier approach using a large panel dataset from US households to estimate the level of energy efficiency.[3] These studies estimate the level of technical as well as allocative efficiency. In this paper we are interested in estimating the level of technical efficiency in the use of electricity.

We use a survey of residential electricity demand conducted on Swiss households in 2005 and 2011. The data include information on appliance stock as well as information on the amount of energy services consumed within a household such as the number of meals consumed, hot water, entertainment, lighting and washing. Therefore, we are able to estimate a sub-vector input distance function, similar to Zhou et al. (2012b), but using household survey data. Thus, to the best of our knowledge, this is the first study that includes energy services in the frontier model and adopts a distance function approach on a disaggregated level to estimate the level of technical efficiency in the use of electricity based on a microeconomic foundation. Further, we investigate in an explorative way if standby reduction practices have an influence on the inefficiency level in the use of electricity. To do that, we aggregate different standby practices into one index.

The rest of the paper is organised as follows. In the next section, we introduce the concept of input-specific efficiency to familiarise the reader with the microeconomic foundation of energy efficiency measurement. We provide an overview of the existing literature on parametric energy efficiency measurement in Section 3. In Section 4 we develop a model for the estimation of the input-specific technical efficiency levels using disaggregated data. In Section 5 we describe the household survey data. The results we present in Section 6, followed by a more detailed analysis of the efficiency level and one of its possible determinants in Section 7. In the final section we offer concluding remarks.

2. Input-specific efficiency in the use of electricity

The residential demand for electricity is a derived demand from the demand for energy services like a warm meal, washed clothes or hot water. Therefore, the demand for residential electricity can be described using standard household production theory whereby households combine electricity and capital goods as inputs to provide services.[4] Since this is a production process, we can attribute a production function to it. In this context, households are assumed to minimise the amount of inputs used to produce a given level of energy services (technical efficiency) and are also expected to choose the combination of inputs that minimise the costs to produce a predefined level of energy services (allocative efficiency). However, there may also be instances where households do not minimise the use of all or one of the inputs.[5] In this paper we are particularly interested in the efficiency in the use of one of the inputs, namely electricity. Therefore, we compare the observed use of electricity with its optimal use. Since producing energy services can be considered to be the result of a production process we can measure how efficiently it is produced, referred to as the productive efficiency.

Productive efficiency can be discussed using the microeconomic theory of production framework. In this context, the radial definition of technical, allocative and overall[6] productive efficiency introduced by Farrell (1957) is an important concept. Based on Farrell's work, Kopp (1981) introduced the concept of an input-specific or single-factor (or non-radial) efficiency measure.[7] In this paper we estimate the technical efficiency because, in comparison to previous studies, we have information on energy services (outputs) and the appliance stock (input). Therefore, it is possible to accurately estimate the level of technical efficiency. The level of overall energy efficiency as estimated in Weyman-Jones et al. (2015) and Alberini and Filippini (2015) is also a possibility. However, with our data we focus our analysis on the level of technical efficiency.

Fig. 1 illustrates the difference between the radial and non-radial approaches. It shows an isoquant for a given amount of energy services produced with different amounts of energy and capital. Assuming that a household produces an energy service at x1, we can define the different concepts. The radial technical efficiency corresponds to the distance between x1 and θx1. In the case of the radial concept, both inputs, capital and energy, will be decreased proportionally with an improvement in efficiency. The non-radial (or energy specific) technical efficiency is displayed in Fig. 1 as the distance between x1 and βx1 or as the ratio of E1 to E3. With this concept we consider only one specific input, only that input will be decreased with an improvement of efficiency, whereas the other inputs are kept constant.

1 Zhou et al. (2012b) call this *Shephard energy distance function*. But in principle it is a sub-vector input distance function, where energy is the only variable input.

2 Note that even Zhou et al. (2012b) use GDP as the output variable in the model instead of energy services.

3 Using panel data Alberini and Filippini (2015) are able to distinguish and estimate the level of persistent and transient energy efficiency. In our study we do not have panel data and it is not possible to make this distinction. The concept of persistent and transient efficiency was introduced by Colombi et al. (2014) and Filippini and Greene (2015).

4 See Deaton and Muellbauer (1980) for a description of household production theory and Flaig (1990) and Filippini (1999) for applications in the demand for electricity.

5 These instances may be explained by the energy efficiency gap, behavioural failures and other barriers.

6 The overall efficiency refers to the technical + allocative efficiency.

7 For a more detailed discussion on the radial and non-radial concepts and as well technical and allocative efficiency in the framework of energy efficiency measurement see Filippini and Hunt (2015).