***Household efficiency in the use of energy: Input demand frontier approach***

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## Overview

Identifying the potential for energy savings is an important prerequisite for successful implementation of energy efficiency measures. Therefore, reliable estimates on the existing inefficiencies are needed. Energy inefficiency could be a result of using old energy-inefficient appliances or heating systems instead of efficient ones, or a result of using home appliances or heating systems sub optimally (Filippini and Hunt, 2015; Alberini and Filippini, 2018). Gillingham et al. (2009) and Allcott and Greenstone (2012) have explored in detail the factors affecting energy-efficiency gap and residential energy inefficiencies throughout economic literature. Broberg and Kazukauskas (2015) have classified the inefficiency in the use of energy in residential sector by its cause, which are market failures such as information inaccessibility, and behavioural failures caused by bounded rationality.

As emphasized, the information on the potential for energy saving is crucial to develop adequate energy policy. In Slovenian residential buildings, the potential for improving energy efficiency and reducing GHG emissions is very high, and can be exploited through retrofits of existing buildings and the replacement of heating systems. The estimated potential is 41% for single-family households and 40% for multi-family households (Long-Term Strategy for Mobilising Investments in the Energy renovation of Buildings in Slovenia, 2015).

This analysis estimates the level of energy efficiency related to the energy use of Slovenian households. Since the residential sector in Slovenia requires around one third of the end energy use, it is important to estimate the scope for energy savings in homes to reduce energy consumption. Our study extends the recent research by Alberini and Filippini (2018) and Boogen (2017) by considering not only consumption of electricity in households, but also other domestic fuels. To estimate the level of energy efficiency in the use of energy in Slovenian residential sector, the study includes energy services in the stochastic frontier model and adopts a distance function approach on a disaggregated level to account for heterogeneity of households.

## Methods

According to the household production theory, demand for energy is derived demand from the demand for energy services (Flaig, 1990, Alberini and Filippini, 2011). It is assumed that households purchase inputs (household appliances and energy) and combine them to produce outputs (warm home, washed clothes, cooked food, hot water etc.). We follow the concept of input-specific efficiency in the use of an input proposed by Kopp (1981). There are several approaches within the production theory to measure input-specific efficiency. The analysis employs an alternative approach proposed by Filippini and Hunt (2011, 2012 and 2015) and Filippini et al. (2014), which is based on household production theory and uses a stochastic frontier analysis (SFA) to estimate the level of energy efficiency related to the use of energy of Slovenian households. In our analysis we use a sub-vector input distance frontier function to estimate the energy saving potential.

The data were taken from the surveys Energy consumption in households in Slovenia conducted by the Statistical office of the Republic of Slovenia (SORS) in 2010 and 2014, which assures representativeness of the sample. The final sample consists of 6,882 Slovenian households. The capital stock (stock of energy appliances) is measured in expected yearly consumption in kilowatt hours estimated by the Energy Efficiency Centre of the Jožef Stefan Institute (EEC IJS). Alternatively, Boogen (2017) used average power while in use in Watts for each appliance as a capacity measure. Based on a wider discussion with experts from the EEC IJS, an average power while in use is not necessarily correlated with appliance’s actual consumption, which is due to various reasons such as working time, type of appliance, type of service, and others. Therefore we believe, that expected annual consumption of the appliance is a better way to estimate energy capacity of the appliance. Detailed estimates are provided according to the type of appliance (e.g. refrigerator can be classical, compact, top-freezer, bottom-freezer, or side-by-side) and its age.

The inputs in the model are the energy input (in kilowatt hours), which combines multiple energy fuels, consumed in household using proposed conversion factors provided by EEC IJS, and the stock of energy appliances, i.e. capital input (in kilowatt hours). The outputs in the model are different energy services and number of household members served. Energy services are measured in physical units such as number of days in a year while in use, number of hours in a year while in use, or others. Additionally, control variables are included in the vector of household characteristics. In the model there are also two error terms introduced to capture random noise and energy inefficiency term. The former is assumed to be symmetric and normally distributed, while the latter is one-sided non-negative and half-normally distributed.

## Results

The descriptive statistics show that in 2014, households consumed most of the energy for space heating (61%), while the other consumptions are significantly lower (water heating 17%, lighting and electrical appliances over 15%, for cooking 5%, and for space cooling less than 0.5%). The largest share among energy sources represents wood with a 42% share, followed by electricity with 26%, heating oil with 12%, natural gas with 9% and district heat with 6%. Breakdown of usage of electrical appliances shown that nearly all households had a refrigerator or refrigerator with freezer (almost 100%), a television (almost 99%) and washing machine (96%). Only 20% of households have air conditioning, of which 41% use them for both cooling and heating. Heat pumps are present in 12% of households and solar collectors in 7% of them.

Preliminary results show relatively low energy efficiency levels. The average efficiency in the use of energy of the whole sample is estimated to be at 54.90%. In the subsample of 2014 it is slightly higher (55.87%) in comparison to the sample from 2010 (54.17%). When comparing expected energy requirements of all appliances between two years, we observe a decrease from 14,196.71 kWh on average per household in 2010 to 13,902.74 kWh on average per household in 2014. This is mostly due to decrease in estimated heating requirements, while conversely, the estimated energy requirements for other appliances (lighting, electrical appliances, cooking appliances) had increased in 2014 compared to 2010.

## Conclusions

In our study we find an average energy inefficiency of around 45%, which is higher than reported in most studies for other countries, such as Boogen (2017), which finds the level of inefficiency of around 20 to 25% for Swiss households in 2005 and 2011, and Alberini and Filippini (2018) with inefficiency of around 27% for US household in 1997-2009. On the other hand, Weyman-Jones et al. (2015) find inefficiency levels varying from 4 % to 43% for Portuguese households in period 1970-2011. These studies focus on electricity consumption, so the higher inefficiency in our study is expected due to inefficiencies related to energy use for heating, which accounts for more than 60% of final household energy use. Our results are well in line with before mentioned estimated potential for energy savings of around 40% for Slovenian households.

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