“Underlying Energy efficiency” in the US Residential Sector and Potential CO2 Savings

Anna **Alberini** and Massimo **Filippini**

Department of Agricultural Economics, University of Maryland,
and
Centre for Energy Policy and Economics (CEPE), ETH Zurich

Centre for Energy Policy and Economics (CEPE), ETH Zurich
and
Department of Economics, University of Lugano, Switzerland

1. Overview

In this paper we present an empirical analysis of the level of “underlying energy efficiency” using a sample of 8745 US households observed over the period 1997-2009. Following Filippini and Hunt (2011, 2013) a stochastic energy demand frontier approach is used to perform a benchmarking of energy use in residential buildings and obtain for each household a measure of the inefficient use of energy. The energy demand frontier model is estimated using several alternate econometric models and estimation techniques. The empirical results indicate a relatively high potential for energy saving for the US residential sector (around 30 %) that could be realized through improvements in the level of energy efficiency of the home. The energy saving potential is greater than that estimated by the Electric Power Research Institute (2009) but similar to that in McKinsey (2009, 2013).

In the second part of the empirical analysis, the indicators of “underlying energy efficiency” are used to determine the potential contribution of an improvement in the level of energy efficiency to the reduction of CO2 emissions by the US residential sector. The results are important within the context of current US energy efficiency and CO2 emissions policy (Energy Efficiency Improvement Act of 2014 (HR 2126)).

This paper makes three contributions to the literature . First, to our knowledge this is the first empirical analysis of the level of energy efficiency of the residential sector that uses household-level, disaggregate data.[1] Second, we provide an estimation of the potential energy savings in the US residential sector made possible by an improvement in the level of energy efficiency using a complete different methodological approach with respect to previous studies published for the US. Finally, when compared with Filippini and Hunt (2013), who use aggregate data, we provide an alternative interpretation of the results that allow us to distinguish between time-variant and time-invariant energy efficiency.

2. Methods

Residential demand for energy is a demand derived for energy services such as a warm house, cooked food, hot water, lighting, etc., and can be specified using the basic framework of household production theory. Households purchase inputs on the market such as energy and capital (electrical appliances, electronics, light bulbs, heating and cooling systems) to produce energy services, which appear as arguments in the household's utility function. [2] In this framework the solution of the utility maximization problem yields the optimal input demand functions for both inputs energy and capital, i.e. a situation characterized by overall productive efficiency. We note that in some cases inefficiency in the use of the inputs capital and energy can be observed in the production of energy services. In these cases, the level of efficiency can be improved by changing the levels and the combination of the inputs.

We posit the following household energy demand function:

[1] Buck and Young (2007) estimated the level of energy efficiency of a sample of Canadian commercial buildings

[2] Approximately 40% of the energy used in a household is for appliances and lighting, whereas space heating, water heating and air conditioning account for 60%.

$$E_{it} = E(P_{it}, Y_{it}, SIZE_{it}, ROOMS_{it}, PERS_{it}, HDD_{it}, CDD_{it},, ELDERLY_{it}, EL\text{-}HEAT_{it}, GAS\text{-}HEAT_{it}, AGEH_{it}, DAC_{i}, DFLOOR_{i},, DCITY_{i}, D_{t}, EF_{it}) \quad (2)$$

where E_{it} is energy consumption in household i in period t, Y_{it} is real income, P_{it} is the real energy price, $SIZE_{it}$ is the size of the dwelling, $ROOMS_{it}$ is the number of rooms, $PERS_{it}$ is the number of people living in the household, $ELDERLY_{it}$ is a dummy variable that indicates the presence of elderly people in the household, $AGEH_{it}$ is the age of the house, $EL\text{-}HEAT_{it}$ is a dummy variable for an electrical heating system, $GAS\text{-}HEAT_{it}$ is a dummy variable denoting a gas heating system, DAC_{it} is a dummy variable that indicates that the home has air conditioning, and $DFLOOR_1$, $DFLOOR_2$, $DFLOOR_3$ are dummy variables indicating the number of floors of the dwelling.

We control for the weather: HDD_{it} measures the heating degree days, and CDD_{it} the cooling degree days. We also control for location: $DCITY_j$ is a series of city dummy variables with which we capture city-specific effects, and D_t is a set of time dummies that capture exogenous technical progress and other exogenous factors common to all households. Finally, EF_{it} is the level of 'underlying energy efficiency' of the household i in year t. A low level of 'underlying energy efficiency' implies an inefficient use of energy (i.e. 'waste energy'), i.e. a situation of productive inefficiency.

In the literature on the estimation of cost or production frontier functions it is possible to identify several different SFA model specifications based on panel data.[3] On one end of the scale there are models that allow estimating the level of persistent (time invariant) inefficiency. On the other end of the scale, we have models that provide information on the level of the transient (time varying) part of the inefficiency. In our empirical analysis we estimate the basic version of the REM proposed by Pitt and Lee (1981) (REM hereafter), a Mundlak version of this model (MREM hereafter) and the true

[3] For a general presentation of these models, see Greene (2008).

random effects model (TREM hereafter). The former two models provide information on the level of persistent inefficiency, whereas the latter gives information on transient inefficiency.

3. Data

The study is based on the American Housing Survey, a longitudinal study conducted by the Department of Housing and Urban Development. The final sample used in this study is an unbalanced panel data set for a sample of 8745 US households observed every two years over the period 1997 to 2009 for a total of 31687 observations.

The sampling units in the AHS are actually homes, not households, and if a household moves out of a dwelling unit and is replaced by another, the AHS continues to collect data from the latter. The AHS gathers extensive information about the structural characteristics of the dwelling, including type, size, heating and cooling system, type of heating fuel, and energy bills. Alberini et al. (2011) merge the AHS data with information about electricity and gas prices at the metro area level, and derive total annual usage of electricity and gas. We use a subset of their data. Households that use heating oil or other fuels are omitted from our analysis.

4. Preliminary Results

In all three models (REM,MREM,TREM) most of the estimated coefficients have the expected signs and are statistically significant at the 1% level. The only exception of the log of income per household in the Mundlak version of the REM (which, however, has the correct sign). Furthermore, the value of the coefficients are similar across all models.

Table 1 provides descriptive statistics for the ‘underlying energy efficiency’ estimates for the 8745 US households obtained from the econometric estimation, showing that the estimated mean and median values of the persistent level of “underlying energy efficiency” is approximately 78%, whereas the time varying component is around 79%. These results indicate that in the US residential sector the potential improvement in the level of efficiency in the use of energy is relatively high. Considering both the level of persistent and time varying "underlying energy efficiency," the US residential sector could save approximately 40% of its total energy consumption. It is interesting to note that these values are more or less in line with the value obtained by McKinsey (2008).

Table 1: Energy efficiency scores

	REM	MREM	TREM
min	0.30	0.31	0.32
max	0.97	0.97	0.94
mean	0.76	0.77	0.81
median	0.78	0.79	0.82

References

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