UNCERTAINTY IN HOUSEHOLD ENERGY CONSUMPTION MODELING: INSIGHTS FROM AN ADVANCED SENSITIVITY ANALYSIS

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(1) Overview

Energy-economy models carry a high level of uncertainty. The techno-economic mechanisms they represent are not established in as robust a manner as those found in natural sciences. Moreover, they are used as forward-looking tools for decision-making; hence, they are subject to uncertainty over future states of the world.

The issue of uncertainty becomes crucial in sectors where decisions are decentralized, such as residential buildings. Energy-economy models, which were first developed to represent energy supply technologies, must be adapted to incorporate a variety of technologies (e.g. HVAC systems, building envelope, lighting systems, etc.) and behaviors (households with heterogeneous preferences and income, industries with different market structures).

Therefore, uncertainty analysis is key to energy-economy models of energy consumption in residential buildings. This paper proposes a sensitivity analysis of one such model, named Res-IRF (Giraudet et al., 2011, 2012). Two characteristics of Res-IRF make it appropriate for a systematic sensitivity analysis. On the one hand, its complex, consolidative architecture creates various sources of uncertainty; on the other hand, its scale is small enough to allow for the use of sophisticated methods of sensitivity analysis while keeping computational cost and time affordable.

The analysis presented here is based on a little known but powerful sensitivity analysis technique: the Morris method. The goal is threefold: (i) explore in breadth and depth the behavior of Res-IRF to refine the assessment of the potential for energy savings in residential buildings; (ii) identify the most crucial inputs to define orientations for data collection and future research; (iii) identify the most robust outcomes to strengthen the messages delivered to policy-makers.

(2) Methods

The aim of sensitivity analysis is to quantify how a change in the model input affects the model output. Several sensitivity analysis techniques have been developed (Saltelli et al. 2008), and the most commonly used is the "perfunctory" (Saltelli 2010) one-at-a-time method (OAT), consisting in changing the value of one input at a time, all the others remaining constant. The main drawback of this method is that it gives derivatives at the base point. These *local* values are relevant for a *global* sensitivity analysis only if some conditions (linearity and additivity) are met.

The Morris method (Morris 1991) is an enhancement of the OAT method which overcomes this drawback. It repeats elementary effects (EEi) calculations for each input throughout the input space domain; using Morris efficient random sampling strategy, which is obtained via a *trajectory based design* (Ruano et al. 2012). The analysis of the EEi distribution for each input factor allows to put importance measures (μ^*) on model parameters and rank them according to their influence on the output. These importance measures approximates well other importance measures given by global sensitivity analyses such as standard regressions coefficients obtained with a Monte Carlo sampling and multilinear regression (Iooss 2011), or Sobol indices (Sobol 1993). A decisive advantage of Morris method is that it is "computationally cheap" (only around 50 simulations by input, compared to about 1000 for Monte Carlo and 10 000 for Sobol method).

Besides, as the trajectory-based design fills the input space, probabilistic results can be computed as well. In the end we are able to provide information on the two crucial questions for a modeler: "If we take into account uncertainties in the inputs, (1) how uncertain are the results? (2) where does this uncertainty come from?"

As Res-IRF is a relatively simple model (compared to big CGEs for example), we are able to take into account *all the parameters* (71 in total) in the analysis and afford a higher number of elementary effects calculations per input as usually recommended (100). The chosen output for the analysis are the total primary energy consumption and the consumption per m2 in old dwellings, both in years 2010, 2020, 2030, 2040 and 2050. As in Ruano et al. 2012, a numerical index is computed to assess the robustness of the results.

(3) Results

First as a general comment, we observe that in Res-IRF, though energy consumption is diminishing over time hand in hand with the energy-efficiency "deposit", the uncertainty propagates through time: results are more uncertain in the long term than in the short/middle term.

In our model, energy prices are the major source of uncertainty both for energy consumption, refurbishments and sufficiency (i.e. variations in the utilization of energy efficient products), and both in the short and in the long term.

The key parameter governing the sufficiency effect, the elasticity of the rebound effect function has also a big impact on the outcome.

This advanced sensitivity analysis also highlights a hidden but decisive aspect of energy-economy models: the importance of calibration through the impacts of calibration targets parameters. For example, the initial rate of retrofitting or the electricity share of heating systems in new dwellings (as we deal with primary energy) proves important impacts on the outcome, especially on the short term.

Besides, though often considered as an unimportant factor in developed countries, the population growth is in our model quite influential on the results outcome. As new dwellings are built to fulfill the housing demand, and they are more energy-efficient than the existing ones, the rate of destruction weights significantly in the outcome uncertainty. In the very long term, a significant share of the dwellings built before 2008 has been refurbished and is energy-efficient. Therefore, the parameter giving the fraction of them that can't be refurbished (because they are historical monuments, or for other reasons) is very influential.

Furthermore, parameters involved in the structure of existing dwellings (such as how much housing are heated by gas, or are in a certain energy-efficiency category) are also quite influential in a lesser extent, especially in the short term.

Finally, a certain number of parameters that made the originality of Res-IRF among residential energy consumption models, such as the learning rate (learning-by-doing process) the information rate (neighbor effect) and the differentiated discount rates (landlord-tenant dilemma) proved less influential as we expected.

(4) Conclusions

Systematic sensitivity analysis shows that the main output of interest of the Res-IRF model, the energy consumption due to space heating in French dwellings in 2050, varies by 50% over the space of inputs tested. Although this seems like a great variability, it is due for the most part to exogenous inputs: future energy prices, which is arguably the most uncertain exogenous input of the model, and population. In contrast, "internal" parameters alone generate less variation. This leads to the conclusion that the model is responsive to exogenous inputs, but has a rather stable internal structure.

Uncertainty analysis allows also highlighting which data should be more accurately estimated to reduce the uncertainties in the model output. In our case, parameters regarding the structure of existing dwellings and the initial retrofitting rate are influential though obtained with perfectible statistical surveys.

Lastly, sensitivity analysis shows that the extensive margin of energy consumption is quite sensitive to variation in inputs. In terms of policy-making, this strengthens the case for government interventions that do not only encourage investment in energy efficient technologies, but also target behavioral change.

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