Global Sensitivity Analysis of an Energy-economy Model of the Residential Building Sector

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Uncertainty associated with modelling such a complex system?

1. The Res-IRF model in a nutshell
2. Quantifying uncertainty: Monte-Carlo analysis
3. Characterizing uncertainty: the Morris Method
Res-IRF in a nutshell
Res-IRF: Scope

• Energy use covered
  – Space heating (2/3 of French household demand)
  – Electricity, natural gas, fuel oil

• Energy efficiency improvements
  – New constructions (standard/low energy/passive)
  – Retrofitting of existing dwellings (including fuel switch)
Res-IRF’s Main Innovations

• All margins of energy use are endogenous
  – Intensity of retrofits
  – Number of retrofits
  – Utilization adjustments (Rebound effect)

• Some barriers to energy efficiency
  – Static: split incentives (discount rates)
  – Dynamic: learning-by-doing, information acceleration
Intensity of Retrofits

\[ PR_{i,f} = \frac{LCC_{i,f}^{-\nu}}{\sum_{h>i} LCC_{i,h}^{-\nu}} \]

Heterogeneous discount rates across landlords and tenants

\[ LCC_{i,f} = CINV_{i,f} + CENER_f + IC_{i,f} \]

Subject to endogenous decrease (learning-by-doing)

Subject to endogenous decrease (peer effects)
Number of Retrofits

Captures heterogeneity in preferences for heating (e.g. sensitiveness to cold)
Utilization Adjustments

Rebound Effect Function

Elasticity -0.5

Data: EDF R&D (see Coyre et al., 2011, ECEEE Proceedings)
Insights into French Policy

France’s Target: -38%

Variation 2008-2020 in primary energy per m²:
- Baseline: -8%
- Tax credit + Soft loans (implemented): -10%
- (implemented) + Carbon Tax + Retrofitting obligation (considered): -19%

€200/tCO₂ in 2010!!!
Quantifying Uncertainty: Monte-Carlo Analysis
Protocol

Randomly pick parameters

Latin Hypercube Sampling
Overall Uncertainty

25% around the median value
Characterizing Uncertainty: the Morris Method
Methods of Sensitivity Analysis

![Diagram showing methods of sensitivity analysis]

- **Local analysis**
  - One-at-a-time
  - Computational cost

- **Global analysis**
  - Sobol
  - Morris (a.k.a. Elementary effects)
The Morris Method: Design

We repeat the operation for \( r \) trajectories \( \rightarrow r \times (k+1) \) simulations

\[ \text{Parameters space} \]

\[ k+1 \text{ simulations} \rightarrow k \text{ elementary effects} \]
Results: Morris Diagram

Measure of interaction

2050 Total Consumption (PE)

Most interacting
Most influential

Sigma

mu*

- Long Term Energy Price
- Differential Investment Costs Scaling (OD)
- Learning Rate
- Short Term Energy Price
- DH Surface (OD)
- Initial Retrofitting Rate
- Energy Class Scaling
- Gas Scaling
- Population Scaling
- MS Optimism (OD)
- Rebound Effect Elasticity
- IC Discount Rate
- Initial Household Density Increase
- Initial Electric Consumption
- Global Investment Costs Scaling (OD)
Parameters Ranking

Top 12 inputs

Rest of inputs

\[
m^* \]

Parameter Rank
Important Parameters: Comment

- **Energy price**
  
  *Somewhat reassuring that the model is sensitive to its main input...but very uncertain parameter in practice!*

- **Initial retrofitting rate**
  
  *Illustrates that calibration is a critical step*

- **Rebound effect elasticity**
  
  *Importance of behaviours*

The model is more sensitive to how the different margins of energy use are disaggregated than to how barriers to energy efficiency are introduced.
Overall, we were quite happy with the results. But...

- Even though all inputs are taken into account, analysis still dependent on the choice of the probability distributions

- Sensitivity specific to one particular output (energy use)

- Sensitivity analysis only captures uncertainty about model quantities, not about model forms