An Agent-Based Model of Retrofit Adoption
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The paper in a nutshell

• Development of an agent-based model to investigate the role of financial, behavioral, and social factors on the household's decision to invest in thermal insulation, used to simulate the effect of various policy schemes

• We use data from the Second consumer market study on the functioning of the retail electricity market in EU (2015) (DG Energy)

• Results suggests that policy leveraging environmental protection in isolation are not effective and that traditional financial incentives are more effective when targeted to low-income households
Motivations

Final energy consumption in the EU, distance to 2020 and 2030 targets

EU 2020 energy efficiency target: 20%
EU 2030 energy efficiency target: 32.5%
Research gaps & Questions

• Research gaps
  • Reasons behind the **observed under investment** largely unexplained by neoclassical economics (Pollitt and Shaorshadze, 2013)
    • The **behavioural** literature highlights the role of behavioural heterogeneity (Fischbacher et al. 2015)
    • The literature on **innovation diffusion** that of social influence in the adoption process (Rogers, 2003)
  • Energy economic models have **limitations** (perfect rationality, homogeneity, no interaction) that affect their usefulness to **policy-makers** (Arthur, 2021)

• Contributions
  • Inclusion of **economic, behavioural** and **social motivations** affecting household's decision to invest in energy renovation
  • Role of economic and behavioural **heterogeneity**, and the non-linear effect of **network-mediated interactions** for policy developments
The model

Agent-based model that embeds the Bénabou and Tirole (2011b) behavioral economic theory into epidemic model to account for the role of heterogeneity and social influence

Adoption \((i, t) = \begin{cases} 1, \text{ if } Z < \frac{(1-\beta)}{2}EB + \beta N \\ 0, \text{ otherwise} \end{cases} \]

\[ EB = (v_i - c_i) \]

\[ N = \frac{n_{adopt,i} \cdot q_i}{n_i} \]

- \(v_i\) - behavioral factor: degree of environmental concern
- \(c_i\) - economic factor: up-front cost of the technology
- \(N\) - social factor: weight that the network of relationship of agent \(i\) has on her choice to invest (Valente, 1996)
- \(q_i\) - imitation: propensity to imitate others’ behavior inversely proportional to individual self-knowledge (Bénabou and Tirole, 2011a)
- \(\beta\) – weighting factor of personal and social components
Data

- Observations of 29,119 households
- EU 28 plus Norway and Iceland
- Individual aged 18 to 95 fully or jointly in charge of paying the electricity bill in their households
- Information on socio-demographic, attitudes toward the electricity market, and adoption of energy efficiency technologies

Source: Second consumer market study on the functioning of the retail electricity markets for consumers in EU (2015)
Data

Categorical variable used as a proxy for income
«Thinking about your household’s financial situation, would you say that making ends meet every month is...?»

Likert-scale variable «It is important for me to save energy for environmental reasons»
## The Baseline Model

<table>
<thead>
<tr>
<th>Networks</th>
<th>Preferential Attachment, Small World High Cluster, Small World Low Cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Adopter</td>
<td>Betweenes, Eigenvector, Marginal, Random</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.0 - 1.0</td>
</tr>
<tr>
<td>$c_i$</td>
<td>0.1 - 1.0</td>
</tr>
<tr>
<td>$v_i$</td>
<td>0.0 - 1.0</td>
</tr>
<tr>
<td>Repetition</td>
<td>100 per setting</td>
</tr>
</tbody>
</table>

- Normalized distribution of households’ financial situation and environmental concern to define $c_i$ (normalized ration of agent’s income and technology costs) and $v_i$
- $y_i < 0.3$ **low-income** households not able to support the financial burden of the investment
- $v_i < 0.4$ **low-environmentally concern** households that can be influence by their neighborhood’s behaviour
Policy simulations

Promoting environmental concern
• Traditional **mass campaign** to increase environmental awareness (Hungerford and Volk, 1990)
• **Targeted norm-based intervention** (Scott et al., 2016). Group’s **heterogeneity** (Mills, 2020) and interaction with a **trusted messenger** to create shared pro-environmental norms (Moseley and Stoker, 2013, Bicchieri and Dimant, 2019)

Financial incentives (Gillingham et al., 2009)
• Simulation of a **100% rebate** for energy efficiency interventions (e.g. Ecobonus 2020 in Italy)
• Comparing its effectiveness based on the targeted population (**random assignment vs low-income households**)
Results

- **Mass campaign**: unintended effect on those who were already environmentally concerned (Dütschke et al., 2018). *One-size-fit-all intervention* might be constrained by individual heterogeneity (Sunstein, 2013).

- **Norm-based intervention**: promote adoption at the community level but limited effect on the whole population. Complement with measures to develop a **collective identity** (Hornung et al., 2019)

Solid line: baseline model.  
Dotted line: mass campaign.  
Dotdashline: targeted norm-based intervention
Results

- Fiscal incentives more effective if target low-income households
- Design fiscal incentives accounting for justice concerns to tackle or limit vulnerability to energy poverty (Boardman, 2012)
- Prevent free riding for those that would have already adopt even in the absence of the incentives (Olsthoorn et al., 2017)

Solid line: baseline model.
Dotted line: randomly assigned rebate.
Dotdashline: targeted low-income households.
Conclusions

• Energy efficiency gap evidence (Jaffe and Stavins, 1994)

• **Behavioral economics**: role of individuals’ heterogeneity in their intrinsic motivation (Bénabou and Tirole, 2011b)

• **Innovation diffusion theory**: role of social structure on which interactions unfold (Rogers, 2010)

• **Agent-based model** grounded in a behavioral economic theory reflecting heterogeneity in households’ economic and behavioral characteristics, and their interactions

• **Simulation** of subsidy-focused and more diverse portfolio of policy instruments (Economidou et al., 2019)

• **Combination** of behaviorally informed and traditional interventions might be more effective in promoting adoption (Ewert, 2020)
Thank you for your attention

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References


• E. Commission. 2018 assessment of the progress made by member states towards the national energy efficiency targets for 2020 and towards the implementation of the energy efficiency directive as required by article 24(3) of the energy efficiency directive 2012/27/eu. *O. J. Eur. Union L*, 2019.

References


References

References


Motivations

• **Renovation Wave** [COM/2020/662 Final] aimed at **double** the annual **energy renovation rate** mainly through the **retrofit of existing building stock**

• Building stock responsible for **40%** of **energy consumption** - **residential building** accounts for **25%** - and **36%** of CO2 emissions in the EU (Tsemekidi Tzeiranaki et al., 2019)

• Energy saving potential unleashed if retrofit intervention includes substantial **thermal insulation** of the building envelop (Berger and Hölzl, 2019)

• It can contribute to **alleviate energy poverty** (Boardman, 2012)

• It is a key-strategy for the **post-COVID 19 recovery** (EC 27 May 2020)
Robustness check

• **Chi squared goodness of t test** results show that the accordance between simulated and empirical distribution of adopters is maximized.

• Results show that the model well reproduce the S-shaped curve of classical **epidemic models** (Eq. 3) (Griliches, 1957).

• Sensitivity analysis of $\beta$
  - $B = 0$ (**economic-behavioral component**): simulated adoption rate **40% higher** compare to the empirical observation.
  - $B = 1$ (**social component**): **underestimation** of the adoption rate dependent on the underlying network structure.

• At the extreme of the parameter space, we miss to capture the relative weight of personal ad social component.