An Agent-Based Model of Retrofit Diffusion: A Behavioral Economic Approach

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Outline

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Motivations

Why is Energy Efficiency in the Residential Sector important?
• Significant contribution to EU 2030 target (EC, 2019a,b)
• Retrofit activity major reservoir of energy efficiency potential (EC, 2019b)

What are the Research Gaps in Energy-Economy Models?
• Behavioral factors (Cattaneo, 2019)
• Consumer heterogeneity (Fischbacher et al. 2015)
• Peers’ pressure (Henry and Vollan, 2014)
Research objective

WHAT?

Simulating diffusion of energy efficiency retrofit at the households level

HOW?

Integrating behavioral economics theory into agent-based model
Model based on Benabou and Tirole (2011) & Griliches (1957)

Reinterpreting the Benabou and Tirole (2011) Behavioral Model

- **Cost of the action** -> Relative retrofit cost
- **Intrinsic motivation** -> Environmental concern (Khan, 2007; Brekke et al. 2008)
- **Peer’s pressure** -> Neighboring influence

Extending the Epidemic Diffusion Model

- **Heterogeneity** in agent characteristics
- **Network structure** (Valente, 1996)
Model

Decision rule

• Weighted sum of economic, behavioral and social motivations

• Adoption conditional on neighbor’s performance (Granovetter, 1978) and sensitivity to difference (Benabou and Tirole, 2011a)

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

\(Z\) uniformly distributed random value between 0 and 1

\[EB = (v_i - c_i)\]
\(v_i\) environmental concern; \(c_i\) relative cost normalized

\[N = \frac{n_{ad,i} + (n_{ad,j}*q_i)}{n_i + n_j*q_i}\]

\(n_i\) and \(n_j\) similar* and different neighbors; \(n_{ad,i}\) and \(n_{ad,j}\) similar and different neighbors’ adopters; \(q_i\) propensity to imitate

* Two agents are considered similar if their level of environmental concern differs less than 0.2
Model

Environment
Small-world (Watts and Strogatz, 1998): tighter and more numerous relationships
Preferential attachment (Barabasi and Albert, 1999): social interactions mediated by a leader

First Adopter
Marginal: limited social impact
Betweens: high social impact
Eigenvector: linked with central nodes

Budget constrain
Low-income households ($y_i < 0.3$) do not adopt due to financial constrains

Motivational constrains
Low environmentally concern households ($v_i < 0.4$) adopt only if more then 50% of their neighbors adopted
Calibration

## Results

### ABM Settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
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<tr>
<td>Networks</td>
<td>Preferential Attachment, Small World High Cluster, Small World Low Cluster</td>
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<td>First Adopter</td>
<td>Betweenes, Eigenvector, Marginal, Random</td>
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<td>β</td>
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<td>α_t</td>
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<tr>
<td>v_t</td>
<td>0.0 - 1.0</td>
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<tr>
<td>Repetition</td>
<td>100 per setting</td>
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Results
Sensitivity Analysis $\beta$

- When $\beta = 1$ only neighbouring influence drives diffusion
- For $\beta = 0$ only the individual component affects the diffusion patterns
- Diffusion slows down as $\beta$ increases:
  - $\beta = 0$ overestimation of diffusion speed
  - $\beta = 1$ underestimation of diffusion speed
Results
Sensitivity Analysis $\beta$

- Results for $\beta = 1$
- Preferential attachment and marginal first adopter diffusion rate lower compared to the central positions of the first adopter
- In small world networks, the effect of $\beta$ is lower and difference across first adopters position does not affect diffusion in a remarkable way
- Effect of the clustering coefficient is not that sharp, slightly ease in adoption in the case of low clustering coefficient

a (preferential attachment)  b (small-world high cluster)  c (small-world low cluster)
Discussion and Conclusions

• Agent based model simulating energy efficient retrofit adoption as a function of economic, behavioral and social motivations

• Our framework merges a behavioural economics theory into an epidemic diffusion model to ensure structural model validity at the micro-level

• Relying only on epidemic and traditional economic models fails to account for important aspects in decision-making processes

• Network topologies resemble the different neighbouring structure:
  • Preferential attachment: detached houses where the imitation process is constrained by the sparse topology of neighbouring houses
  • Small world networks: apartments building, where imitation can more easily affect retrofit decisions due to the tight relationship in these social structures
Discussion and Conclusions

• Propensity to imitate
  • Heterogeneity in imitation propensity stochastically affect retrofit decision
  • Homogeneity in their propensity to imitate ease adoption only if there is at least a minimum percentage of households that are willing to adopt

• In highly homogeneous neighbouring structure, policy makers can design norm-based interventions to shift preferences in favour of energy retrofit investments (Sparkman and Walton (2017))

• Budget constrain: promote a traditional financial intervention through direct payments for low-income households
Thank you for your attention

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Agent-based models of Innovation diffusion

• **Agent-based model**: micro level behavior, preferences heterogeneity, social influence (Kiesling et al. 2012; Rai and Henry, 2016)

• **Social network**: in small world topologies faster diffusion (Delre et al. 2007; Choi et al. 2010; Bohlmann et al. 2010); role of hubs both positive (Delre et al., 2010) and neutral (Bale et al., 2013) effects.

• **Social psychological theory**: electric vehicle (Krebs, 2017; Kangur et al., 2017; Siebert et al., 2017), heating systems (Sopha et al., 2011), and water saving technologies (Schwarz and Ernst, 2009); technology diffusion (Janssen and Jager, 2002), energy demand (Gotts and Polhill, 2017).

• **Behavioral economic approach**: electricity consumption (Siebert et al., 2017) energy related investments (Silvia and Krause, 2016).
References

References


