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Dipartimento di Economia e Statistica *Cognetti de Martiis*

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

Chersoni G., Della Valle N.. Fontana M.

Outline

Motivations

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Model

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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 at. 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)

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

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

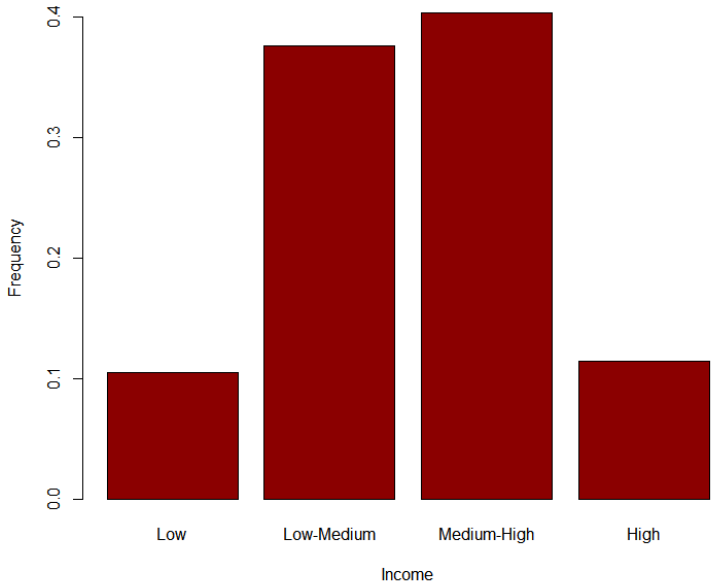
Budget constrain

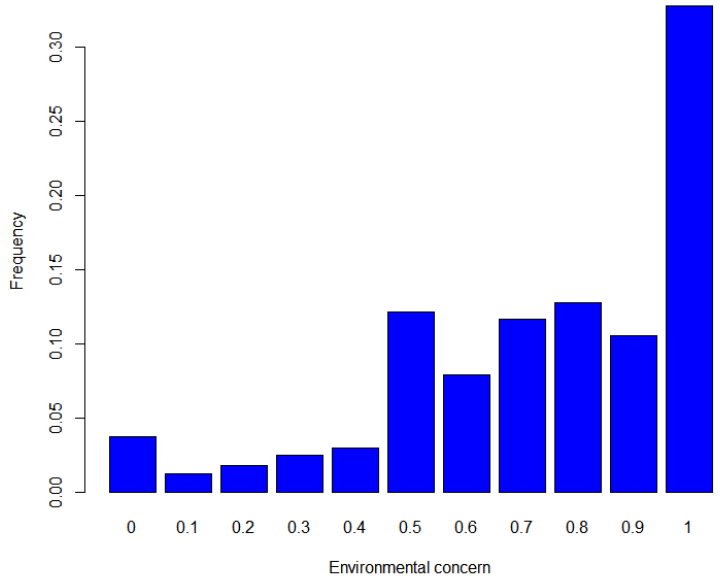
Low-income households ($y_i < 0.3$) do not adopt due to financial constrains

Motivational constrains

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

Calibration





Variable	n	mean	sd	median	min	max	range	skew	kurtosis
Income (y)	24266	0.51	0.28	0.67	0.00	1.00	1.00	-0.04	-0.55
Environmental concern (v)	24266	0.74	0.27	0.80	0.00	1.00	1.00	-1.00	0.36

Source: Second Consumer Market survey (DG, Energy and Transport 2015)

Results

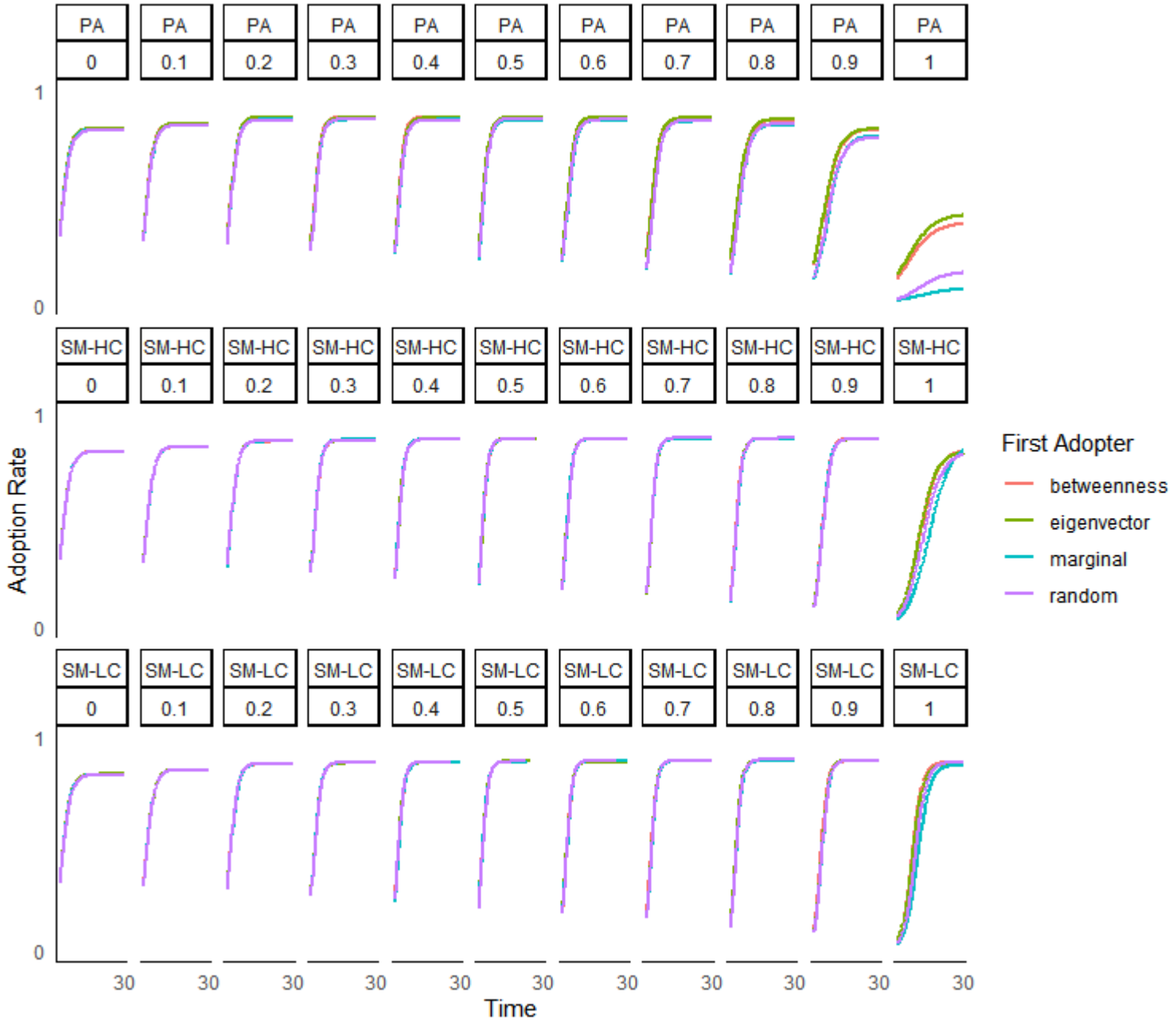
ABM Settings

Networks	Preferential Attachment, Small World High Cluster, Small World Low Cluster
First Adopter	Betweenes, Eigenvector, Marginal, Random
β	0.0 - 1.0
c_i	0.1, 0.3, 0.6, 1.0
v_i	0.0 - 1.0
Repetition	100 per setting

Results

Sensitivity Analysis β

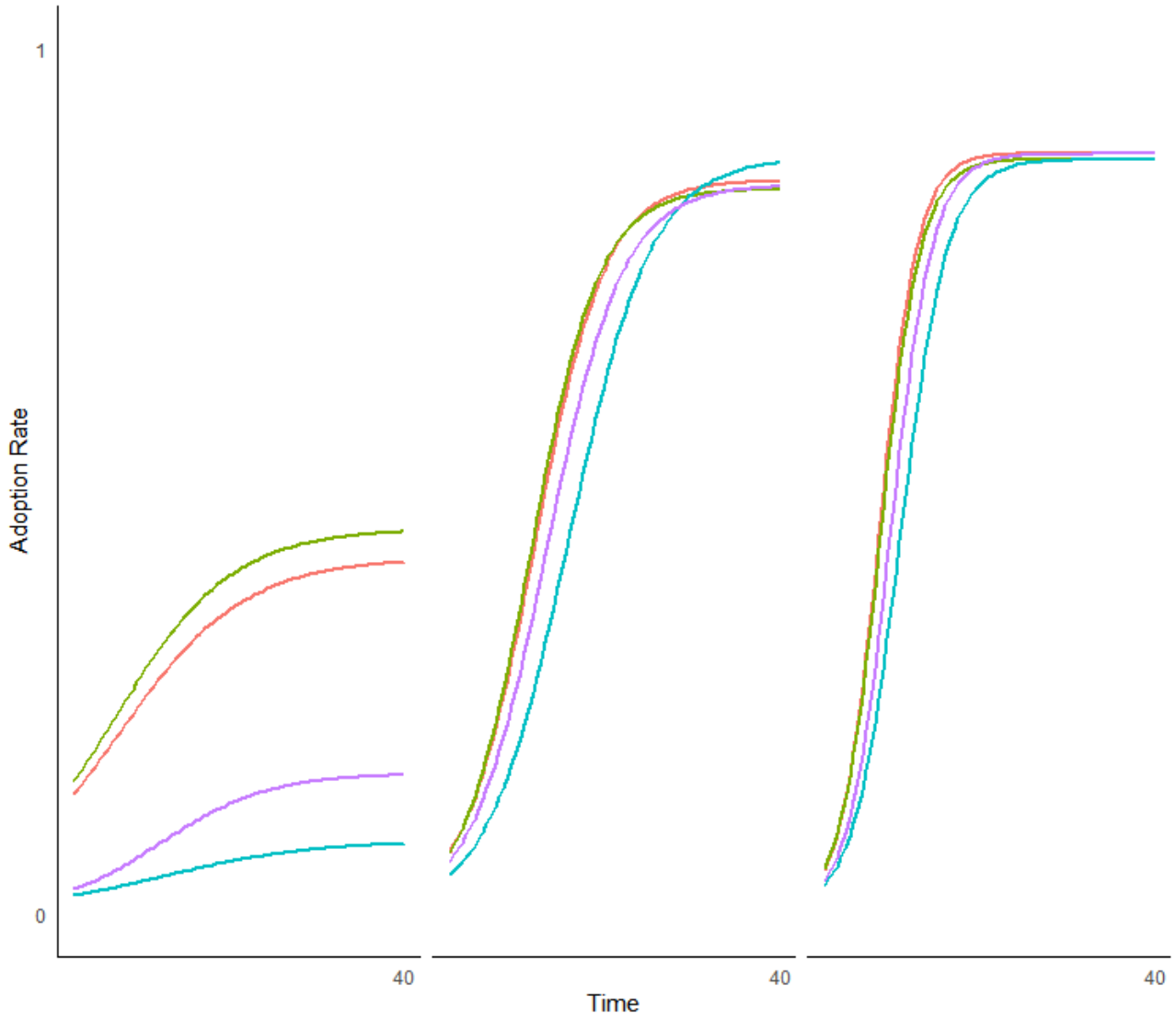
- When β= 1 only neighbouring influence drives diffusion
- For β = 0 only the individual component affects the diffusion patterns
- Diffusion slows down as β increases:
  - β = 0 overestimation of diffusion speed
  - β = 1 underestimation of diffusion speed



Results

Sensitivity Analysis β

- Results for β = 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 β 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 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, were 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 here 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

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Thank you fro your attention

giulia.chersoni@unito.it

Literature Review - back

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).

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