An Agent-Based Model of Retrofit Adoption

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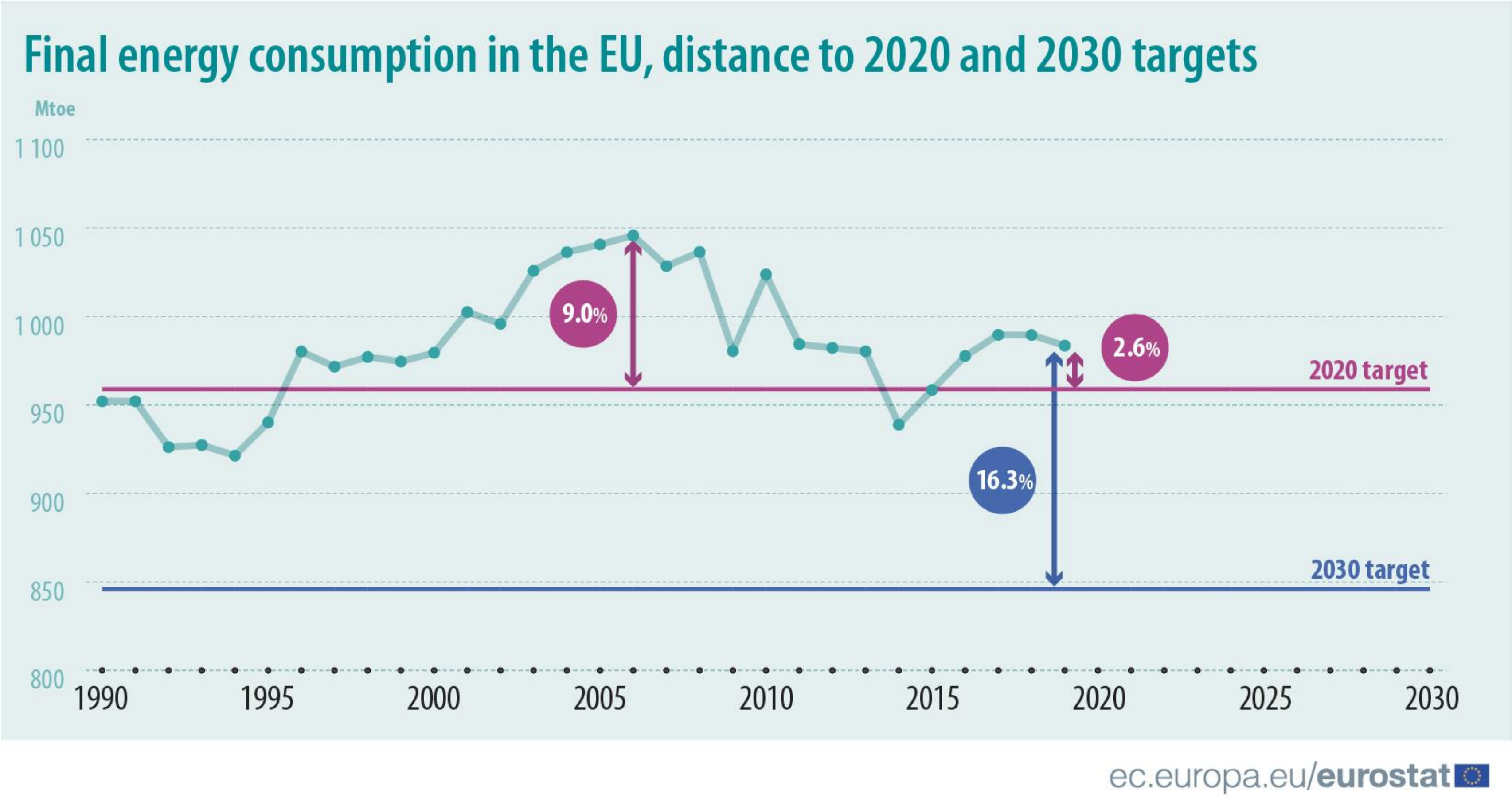
The paper in a nutshell

- 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



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

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

$$EB = (v_i - c_i)$$

$$N = \frac{n_{adopt,i} * q_i}{n_i}$$

v_i - behavioral factor: degree of environmental concern

c_i - economic factor: up-front cost of the technology

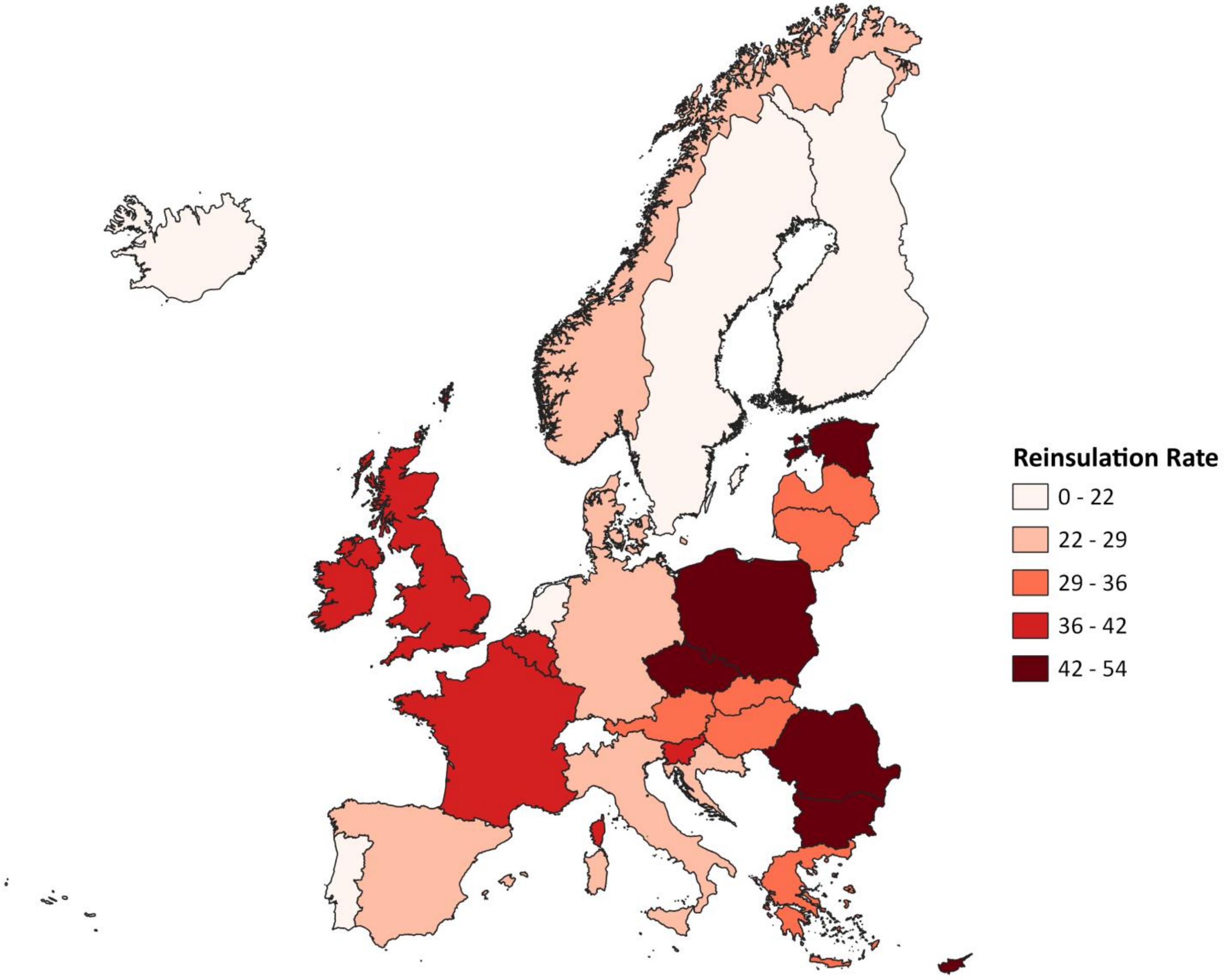
N - social factor: weight that the network of relationship of agent i has on her choice to invest (Valente, 1996)

q_i - imitation: propensity to imitate others' behavior inversely proportional to individual self-knowledge (Bénabou and Tirole, 2011a)

β – weighting factor of personal and social components

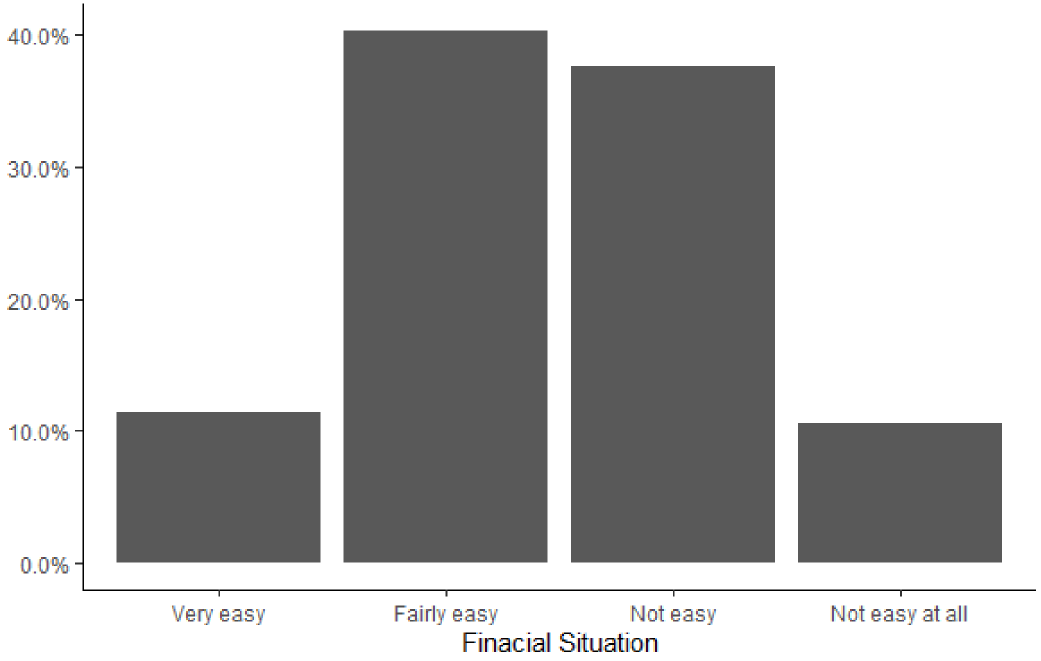
Data

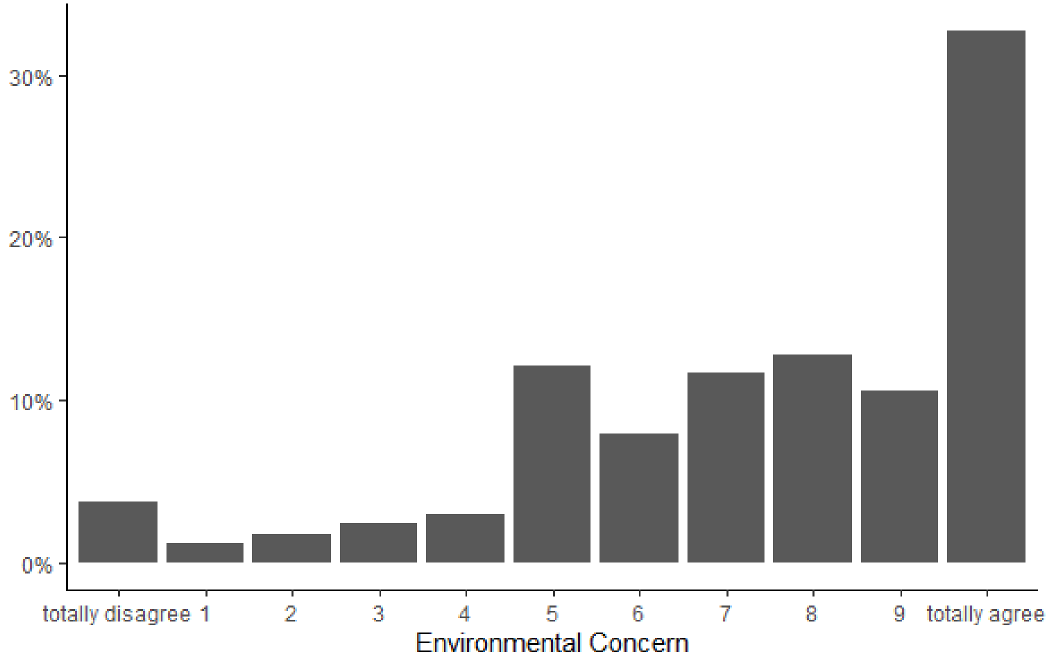
- Observations of **29,119** households
- EU 28 plus Norway and Iceland
- Individual aged 18 to 95 fully or jointly **in charge of paying the electricity bill** in their households
- Information on **socio-demographic**, **attitudes** toward the electricity market, and **adoption** of **energy effiency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

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 - 1.0
v_i	0.0 - 1.0
Repetition	100 per setting

- 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

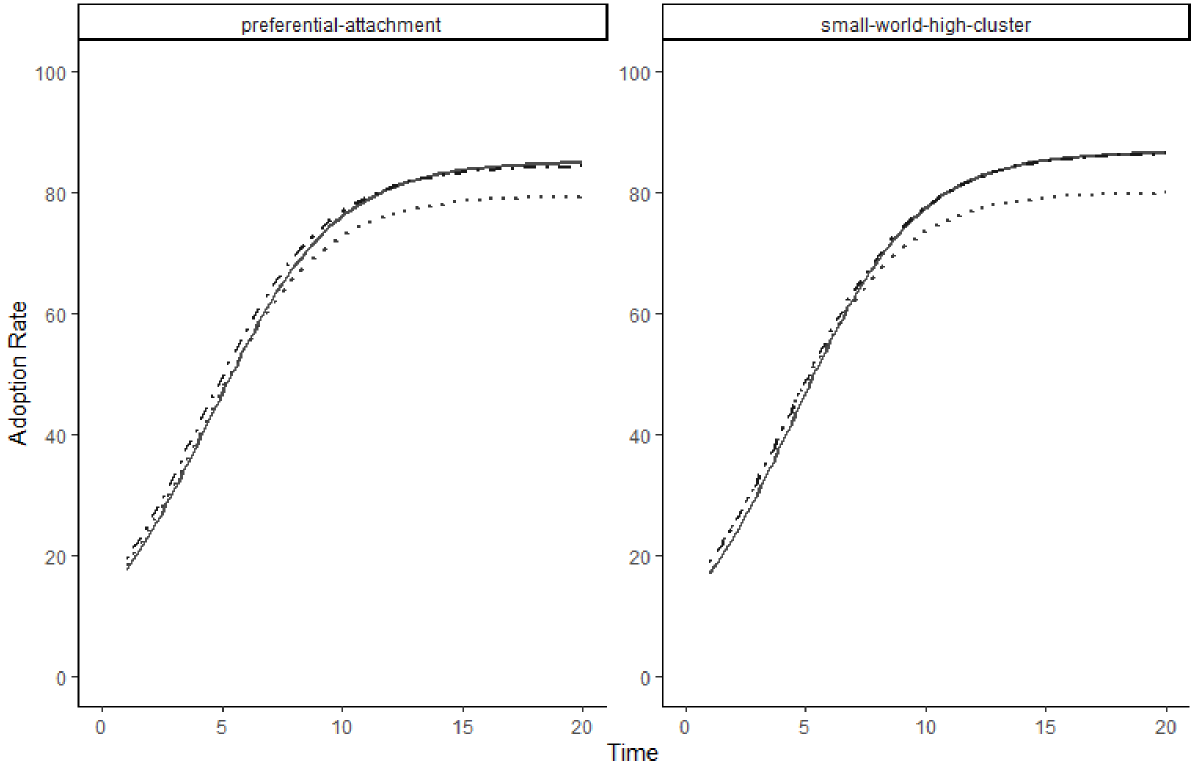
- Traditional **mass campaign** to increase environmental awareness (Hungerford and Volk, 1990)
- **Targeted norm-based intervention** (Scott et al., 2016) . Group's **heterogeneity** (Mills, 2020) and interaction with a **trusted messenger** to create shared pro-environmental norms (Moseley and Stoker,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

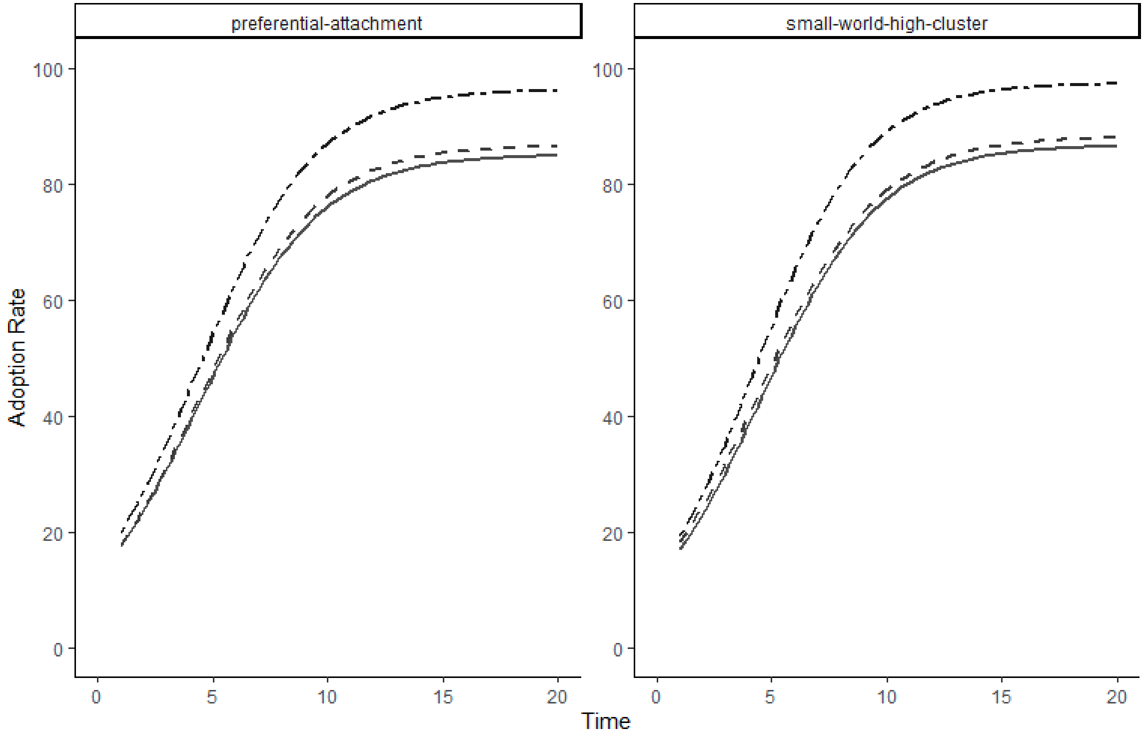
- **Mass campaign**: unintended effect on those who were already environmentally concerned (Dütschke et al., 2018). *One-size-fit-all intervention* might be constrained by individual heterogeneity (Sunstein, 2013)
- **Norm-based intervention**: promote adoption at the community level but limited effect 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)

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Thank you for your attention

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References

- W. B. Arthur. Foundations of complexity economics. *Nature Reviews Physics*, pages 1–10, 2021.
- R. Bénabou and J. Tirole. Identity, morals, and taboos: Beliefs as assets. *The Quarterly Journal of Economics*, 126(2):805–855, 2011a.
- R. Bénabou and J. Tirole. Laws and norms. Technical report, National Bureau of Economic Research, 2011b.
- T. Berger and A. Höltl. Thermal insulation of rental residential housing: Do energy poor households benet? a case study in krems, austria. *Energy Policy*, 127:341–349, 2019.
- C. Bicchieri and E. Dimant. Nudging with care: The risks and benets of social information. *Public choice*, pages 1–22, 2019.
- B. Boardman. Achieving zero. *Delivering future-friendly buildings.(University of Oxford's Environmental Change Institute, Oxford, United Kingdom, 2012)*, 2012.
- E. Commission. 2018 assessment of the progress made by member states towards the national energy eciency targets for 2020 and towards the implementation of the energy eciency directive as required by article 24(3) of the energy eciency directive 2012/27/eu. *O. J. Eur. Union L*, 2019.
- N. DellaValle. People's decisions matter: understanding and addressing energy poverty with behavioral economics. *Energy and Buildings*, 204:109515, 2019.

References

- E. Dütschke, M. Frondel, J. Schleich, and C. Vance. Moral licensing—another source of rebound? *Frontiers in Energy Research*, 6:38, 2018.
- M. Economidou, V. Todeschi, and P. Bertoldi. Accelerating energy renovation investments in buildings. *EUR–Scientic and Technical Research Reports. Ispra: Joint Research Centre (JRC)*, 2019.
- B. Ewert. Moving beyond the obsession with nudging individual behaviour: Towards a broader understanding of behavioural public policy. *Public Policy and Administration*, 35(3): 337–360, 2020.
- K. Gillingham, R. G. Newell, and K. Palmer. Energy eciency economics and policy. *Annu. Rev. Resour. Econ.*, 1(1):597–620, 2009.
- Z. Griliches. Hybrid corn: An exploration in the economics of technological change. *Econometrica, Journal of the Econometric Society*, pages 501–522, 1957.
- J. Hornung, N. C. Bandelow, and C. S. Vogeler. Social identities in the policy process. *Policy Sciences*, 52(2):211–231, 2019.
- H. R. Hungerford and T. L. Volk. Changing learner behavior through environmental education. *The journal of environmental education*, 21(3):8–21, 1990.

References

- A. B. Jae and R. N. Stavins. The energy-eciency gap what does it mean? *Energy policy*, 22 (10):804–810, 1994.
- A. Mani, S. Mullainathan, E. Shar, and J. Zhao. Poverty impedes cognitive function. *science*, 341(6149):976–980, 2013.
- S. Mills. Personalized nudging. *Behavioural Public Policy*, pages 1–10, 2020.
- A. Moseley and G. Stoker. Nudging citizens? prospects and pitfalls confronting a new heuristic. *Resources, Conservation and Recycling*, 79:4–10, 2013.
- M. Olsthoorn, J. Schleich, X. Gassmann, and C. Faure. Free riding and rebates for residential energy eciency upgrades: A multi-country contingent valuation experiment. *Energy Economics*, 68:33–44, 2017.
- M. G. Pollitt and I. Shaorshadze. The role of behavioural economics in energy and climate policy. In *Handbook on energy and climate change*. Edward Elgar Publishing, 2013.
- E. M. Rogers. *Diusion of innovations*. Simon and Schuster, 2010.
- J. Rosenow, F. Kern, and K. Rogge. The need for comprehensive and well targeted instrument mixes to stimulate energy transitions: The case of energy eciency policy. *Energy research social science*, 33:95–104, 2017.

References

- M. G. Scott, A. McCarthy, R. Ford, J. Stephenson, and S. Gorrie. Evaluating the impact of energy interventions: home audits vs. community events. *Energy Eciency*, 9(6):1221–1240, 2016.
- C. R. Sunstein. Impersonal default rules vs. active choices vs. personalized default rules: A triptych. *Active Choices vs. Personalized Default Rules: A Triptych (May 19, 2013)*, 2013.
- S. Tsemekidi Tzeiranaki, P. Bertoldi, F. Diluiso, L. Castellazzi, M. Economidou, N. Labanca,
- T. Ribeiro Serrenho, and P. Zangheri. Analysis of the eu residential energy consumption: trends and determinants. *Energies*, 12(6):1065, 2019.
- T. W. Valente. Social network thresholds in the diusion of innovations. *Social networks*, 18(1): 69–89, 1996.
- T. W. Valente. Network interventions. *Science*, 337(6090):49–53, 2012.

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 CO_2 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 Höltl, 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 β
  - 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