An agent-based model of retrofit diffusion

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Background

In 2017, the building stock was responsible for, approximately, 40% of energy consumption and 36% of CO2 emissions of the European Union(Commission, 2010), which has spurred the EU to increase the energy efficiency targets up to 32.5% in 2030 (EU, 2018, 2013). In particular, the residential sector is the sector with the highest available energy saving potential, accounting for the greatest share (i.e. 27%) of energy consumption (Commission, 2017). To this purpose, the European Commission lunched a new strategy to double annual energy renovation rate, giving major attention to retrofit of the existing building stock (Commission, 2020). However, the related policy measures have somehow proven unsatisfactory. The latest assessment on the progress made by Member States towards the energy efficiency targets shows that the EU 2020 target is unlikely to be met, a trend that makes the EU 2030 target more difficult to achieve (Commission, 2019). In the face of this evidence a better understanding of the factors that shape the households decision to invest in energy-efficient technologies seems central to provide a solid foundation for policy-makers and, consequently, to achieve the EU energy efficiency target (Mundaca et al., 2010).

The literature on the topic is variegated. In addition to the financial constraints versus savings (Michelsen and Madlener, 2013), recent studies have highlighted the role of behavioral attitudes (Frederiks et al., 2015; Wilson et al., 2015; Friege and Chappin, 2014) and inter-personal influence (Rogers, 2010; Valente, 1996; Young, 2009) on the adoption decision. In particular, households' level of environmental concern has been proven to influence energy efficiency technology adoption

(Kahn, 2007; Prete et al., 2017; Abu-Elsamen et al., 2019; Bashiri and Alizadeh, 2018; Bergek and Mignon, 2017), which is defined in the behavioral literature (i.e.(Whitmarsh and O'Neill, 2010)) as the way individuals internalize the benefits for the environment associated to their adoption decision (Achtnicht, 2011).

Aim

While buildings' renovation includes a variety technologies such as insulation, heating and cooling systems, and lighting in what follows we focus on thermal re-insulation as a proxy for retrofitting. In the present study, we develop an agent-based model simulating the decision-making process behind retrofit adoption of a heterogeneous population of agents interacting in a network-based structure. The possibility to represent network structures that affect the time path of diffusion rate (Rogers, 2010; Valente, 1996), and the capacity to represents micro level behavior as prescribed by behavioral theory (Rai and Henry, 2016) are the main strength of this methodology and enables us to simulate the process behind energy retrofit adoption.

Method

In our model the decision-making process replicate the Bénabou and Tirole (2011) structure, where the adoption process is influenced by economic, non-economic and social factors. The agent-based structure is similar to the model of Chersoni et al. (2020) that we apply to simulate retrofit adoption at the household level to study the joint and separate effect of the three factors on the re-insulation choice. We calibrate the model with the cross-sectional data on 29.119 European households drawn from the Second Electricity Market Study (DG Consumer and Transport, 2015) that investigates electricity market functioning for consumers in the EU.

First, we collect information on household financial situation (i.e. a categorical variable divided in 4 categories), a proxy for income used to account for the up-front costs that negatively affect the likelihood to invest (Schleich et al., 2016), especially for low-income households (Mani et al., 2013; DellaValle, 2019). Second, we gather data on households' environmental concern (i.e. a likert-scale variable that ranges from 0 (strongly disagree) to 1 (strongly7 agree)) to model the less material interests that drives retrofit adoption, in particular the importance that each household gives to energy savings due to environmental reasons. Finally, we impose different inter-personal network in order to simulate the process of the mouth-to-mouth transmission of information about re-insulation, and the imitative drive.

Preliminary results

We first conduct a robustness check. Our model reproduces the expected patterns: the typical S shaped curve is obtained when the adoption is driven only by social influence (Rogers, 2010), and the distribution of the net perceived intrinsic benefit of acquiring the innovation (i.e. trade-offs between economic and non-economic drivers) confirms that the model correctly reproduces the decision rule adopted.

Second, starting from the observed retrofit adoption rate (i.e. 34%), we conduct a validation exercise to find the parameter values that maximize the fit between simulation and observed data[1]. Results shows that in small-world networks with high-clustering coefficient, marginal position of the first adopter, the absolute difference between diffusion level observation and model results is minimized.

Finally, in order to draw some policy conclusion, we aim to simulate different types of policies to assess their effect on the adoption rate in order to met EU 2030 energy efficiency target. In particular, two types of policy based on "awareness raising" (i.e. increasing the level of environmental concern) will be simulated.

Conclusions

Energy efficiency investments should in principle result in long-run cost savings, bu there are still untapped opportunities to reduce energy costs through increased energy efficiency (e.g. energy efficiency gap (Jaffe and Stavins, 1994)). While remaining unsolved in neoclassical economics (Pollitt and Shaorshadze, 2013), households' under-investment in energy efficiency measures has been well tackled within the field of behavioral economics. In this regard, the energy efficiency gap can be explained by looking at individuals' heterogeneity in the degree of their investment inefficien-

[1]Even if the model is capable of reproducing the pattern observed, it does not explain the mechanism behind it: there might be other mechanisms that lead to the same outcome (Vu et al., 2020)

cies and their internalization of externalities (Allcott and Greenstone, 2012; Schleich et al., 2016; Fischbacher et al., 2015). Furthermore, it is largely acknowledged that social influence reinforces technology adoption and that potential adopters that are in sparse clusters or are locate in marginal area of the social networks might not be affected by peer pressure (Valente, 1996). From a policy perspective, a review of policy efforts (see (Mundaca et al., 2019)) to address the low up-take of low-carbon energy technologies, shows a clear orientation towards technology market development (mostly subsidies) and market failures (particularly, information asymmetries), while efforts addressing behavioural anomalies are the exception. In this study we introduced an agent-based model of innovation diffusion grounded in a behavioral economic theory that enables to simulate how innovation diffuses and collective behavior emerges. In particular, by accounting for economic, behavioral, and social factors, it is possible to derive interesting findings to establish under which scenarios policy interventions might effectively shape agents' retrofit decisions to achieve the EU 2030 energy efficiency target.

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