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DOI
10.1007/978-3-030-61503-1_45

Publication date
2021

Document Version
Final published version

Published in
Advances in Social Simulation - Proceedings of the 15th Social Simulation Conference, 2019

Chapter 45
EMLab-Consumer—Simulating Energy Efficiency Adoption Decisions of European Households

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Abstract This paper introduces EMLab-Consumer, an agent-based model developed in the H2020 project Cheetah, on energy efficiency of households. The model builds on the theory of planned behavior, a large European survey and a variety of choice models generated from the same survey. It studies adoption of a number of energy efficient appliances and heating systems in 8 EU countries, under a variety of policy interventions. The paper describes the model and first outcomes on smart thermostats.

Keywords Energy efficiency · Households investments · Agent-based modelling · Choice models · Survey

Introduction

EMLab-Consumer

A recent review of studies using agent-based modelling on energy efficiency decisions in households showed studies still have a rather narrow focus in terms of barriers modelled (lack of capital, a lack of information, high upfront cost), on subsidies, technology bans and information campaigns and particular residential technologies [1]. Earlier work shows the role of non-financial criteria used in the decision-making of energy efficiency and energy reduction [2, 3].

This paper introduces EMLab-Consumer, an agent-based model that simulates household investments in appliances and heating systems. The model contains different types of agents: households, suppliers, appliances and technologies. Households own appliances, e.g. a thermostat, a fridge and a heating system. Over a period of decades, households make use of their appliance and invest in replacement. They also interact with friends: the households are embedded in a social network and

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P. Ahrweiler and M. Neumann (eds.), *Advances in Social Simulation*,
Springer Proceedings in Complexity,
https://doi.org/10.1007/978-3-030-61503-1_45

exchange preferences regarding energy efficient technologies. Technologies define how energy efficient the appliances are. Appliances are the actual items households buy, which can be a fridge, thermostat or heating system. As these appliances break down over time, the household may decide to replace it while more efficient technologies appear on the market.

When a household decides to replace an appliance, they decide on which technology to purchase and where to buy this. The simulated logic is based on utility functions from choice experiments generation from the Cheetah survey, combined with elements from the theory of planned behavior: in their decision households are limited in the number of options they consider, the amount of shops they visit and they are also influenced by their friends. Technologies may differ in size, volume, capacity, energy label, electricity usage. Households consider the properties of the current appliance they are replacing.

Various policies can be applied within the model, to study their effectiveness and efficiency. Some policies may affect retail prices through the provision of subsidies, while others may affect the options that are seriously considered by the households or the options that are allowed on the market.

Outline

The article is structed as follows: in secttion "EMLab-Consumer" describes the model, in section "Adoption of Smart Thermostats: 8 EU Countries – Subsidies" gives first results. The paper ends with conclusions and an outlook.

EMLab-Consumer

Overview

A brief explanation of a run is shown in Fig. 45.1 (previous page). A household starts out having certain appliances. They check if one of their appliances is broken or if they just want to replace one of their current appliances other reasons. If this is the case, they first select the shops at which they would like the buy their appliances. Based on the stock of these shops they select the options for which they determine their utility. Based on among others the utility the choice for a certain appliance is made. This process goes on for each household till the simulation stops. Technologies improve over time and policies affect these decisions.

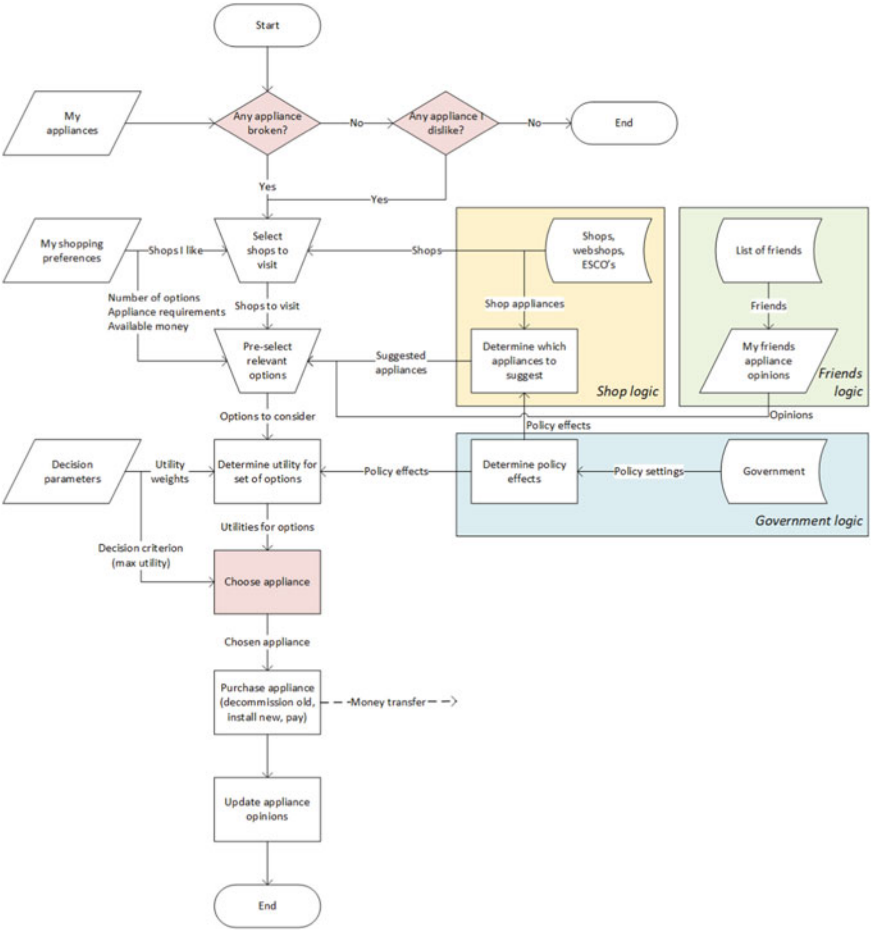

Fig. 45.1 Flowchart of a run with EMLab-Consumer

Agent Types

The first breed are **households**. They are the ones that own the appliances and that have to decide which new appliance to buy or lease and where to do this. Each household has a large number of characteristics, influencing their decision. The households also have general restrictions for the appliances they buy, some of which are based on the appliances they owned at the start of the run. Households are part of a social network. They are set in a scale free network. This means the size of the network doesn't influence the properties of the network. A household has a value assigned for the "minimal number of friends they have". During the model set-up, they can make more friends. After the set-up the number of friends remains the same. Whether you start a friendship with someone is based on "preferential attachment".

This means that if someone already has a lot of friends, the chances are higher that you want to become friends with them.

The **suppliers** are another breed. They store the appliances at their shop. Here the households can buy the appliances they want. Each supplier has their own stock of specific appliances, which they are connected to through links. Suppliers also create links with the households they sell their appliances to. There are three types of suppliers: web shops, shops and ESCO. After a type of supplier sells an appliance to a household, they become the "preferred supplier" of that household. A household then also takes the color of their last preferred type of supplier.

The third breed are **appliances**. This is what suppliers sell and households buy. There are three types of appliances in this model: fridges, thermostats and heating systems. TVs and washing machines can be added to the model later on. Appliances have a certain lifetime. At the end of its lifetime the device breaks down. Its status then changes from "operating" to "decommissioned". The household then has to decide on a replacement from a supplier, who's appliances have the status "for sale". After the household has decided on an appliance, it is ordered and bought through establishing a link between the household and the appliance. The status of the appliance is set to "operating" again.

The fourth and last breed are the **technologies**. They define how energy efficient the appliances are. Newer and more efficient technologies are introduced to the market every other year. Older technology models are sold with discounts. Each technology has a certain energy label, which states how energy efficient they are. The color of the technology represents its label. The technology an appliance has, influences a household's decision on which device they buy. Each household only considers appliances of a certain label.

Households Decision Making Scheme

When the old appliance of a household breaks down, they have to decide on which new appliance they get and where. This is the key process of the model and is influenced by a large number of factors. As the first step a household selects the suppliers, at which stores they want to get their appliance. Each household has a list of suppliers they consider. The selection for this list is influenced by the various options of "supplier selection" to choose from in the facility screen. These options are: "having the same supplier"," having the same type of supplier" or "considering all suppliers". This gives a longlist of all the available appliances in the current year those suppliers hold.

Next in choosing an appliance there are some general technology-based restrictions applied to the list of appliances these suppliers have to offer. These are the following:

- A new TV should have at least the same width diagonally, as people don't want a smaller TV than they already had.

- A new fridge cannot be much bigger than the old fridge, because then it would not fit in the same space anymore.
- A new washing machine is selected on whether its size is reasonable for the households size.

The outcome of applying these restrictions on the previous list of appliances available by the chosen suppliers is the 'long list'. Next a number of these appliances on the "long list" will be added to the "short list". The initial short list is a selection of the suppliers products he chooses for the customer. The shortlist is then expanded, when a household asks their friends and neighbours which appliances they own. Some of these appliances are then added to the 'short list', if they also were on the households "long list" already. Each household has an assigned value for the number of options that can be on their "short list".

Utility Functions from Choice Experiments

Finally, the appliance a household buys is chosen from the 'short list;', based on the utility functions which are generated on the basis of the Cheetah survey. For each type of appliance, a utility function is constructed, the parameters are specific for the countries that are part of the survey. This section will further specify which aspects are considered when buying an appliance. Details regarding the utility functions and parameter values are adopted from [4].

There are several variables that influence which **fridge** households buy. First of all the size of their family. A second contributing factor is the income of the household. The environmental behaviour of a household in also included in the function. Households rate *volume* of the fridge in litres, the length of the *warranty* in years. Furthermore, the energy label of the fridge is taken into consideration and whether a subsidy is available, and, finally, the customer rating of the fridge.

Several parameters affect the **heating system** that households buy. First of all, the *price* of the heating system is important, including any rebate. Second there is the *age* of the buyer. The values of the *subsidies* from the government and the energy provider in Euros and the *expected cost savings* in Euros the new heating system provides are relevant. The installation time in days and the duration of the warranty in years are also included.

The variables that influence which **thermostat** people buy are: their *age,* their income*,* the net *price* of the thermostat, whether it is *recommended* by an independent expert*,* or by the energy provider, whether it is *remote controlled* and whether is *displays* the energy saving when the temperature is modified.

The Final Decision

The Cheetah survey also concluded that households are limited in the number of options they consider, they consider some of those that friends have, they can limit the number of shops they visit, which all are in line with the theory of planned behaviour [5]. The utility is calculated for a limited set of options, accordingly. Optionally, 'alpha' can be used alter the degree in which the results of the utility functions influence the decision on the appliance. High values of alpha cause the probability that a household chooses the appliance with the highest utility value to approach 100%. When the alpha is one, the probability of each appliance being chosen is exactly according to the utility values. When alpha is 0, appliances are chosen at random.

Policies

Within the model there are various ways to influence the environment in which the behavior takes place. There are also various policies that can be enabled, and modified specifically for each technology type. One of the policies influences which labels are allowed over the years for each type of appliance. In some policy options the minimum allowed energy label of an appliance gets raised faster, while during other options the minimum energy allowed label stays consistent for a longer time.

Another policy measure is the subsidy for households, when buying an appliance of certain labels. The amount of money, the number of years the subsidy is given, the minimum label of appliance it applies for and the type of household it applies on (none, low-income or all households) can be changed by sliders on the interface. The subsidy influences the households' choice in appliance, as it makes buying a more sustainable option more attractive.

Implementation and Data

The model is implemented in NetLogo. The model is data-free and all parameters, houseshold data, technology data, utility function data, and default policy parameters are read from text files at the start of the simulation. The model combines data from many sources (appliance data on the basis of public websites, household data from a large survey, etc.) The setup of the model allows for expansion in terms of policies, technology types, etc.

The model code is published on https://github.com/ejlchappin/emlab-consumer and through https://emlab.tudelft.nl.

Adoption of Smart Thermostats: 8 EU Countries – Subsidies

Simulations for each country of the adoption of smart thermostats are illustrated below (Fig. 45.2). These are results from over 170,000 runs, varying country, subsidy levels, whether the subsidy is only available to poor households or not. Results of other technologies are not presented in this paper, but are included in the same set of runs, which explains the high number of simulations.

Households consider purchasing a smart or regular thermostat using the utility function conceptualized earlier. As the initial conditions vary (e.g. the properties of households, the benefits they may have from a smart thermostat, whether they own a smart thermostat already), as well as the utility function parameters, the adoption curve for the countries differ, as well as the effect a subsidy has.

First results show differences in penetration rates, where Romania shows the largest adoption potential, and Poland the lowest. Furthermore, the effect of subsidies appear (almost) none in Romania, Germany, only little in Italy, Spain, Sweden and a somewhat effect in France, Poland, Sweden and the UK. The effect of the subsidy level varies: for the UK a subsidy of 30 Euros is efficient, whereas in Sweden and Poland there is an additional gain to go to 60 Euros.

This illustrates that within exactly the same model, location-specifics matter a lot, details with how a subsidy is implemented. In general, the effect of a subsidy is limited, which suggests the non-financial aspects of the decision, the fact that there still are up-front costs, and other barriers captured implicitly in the utility functions.

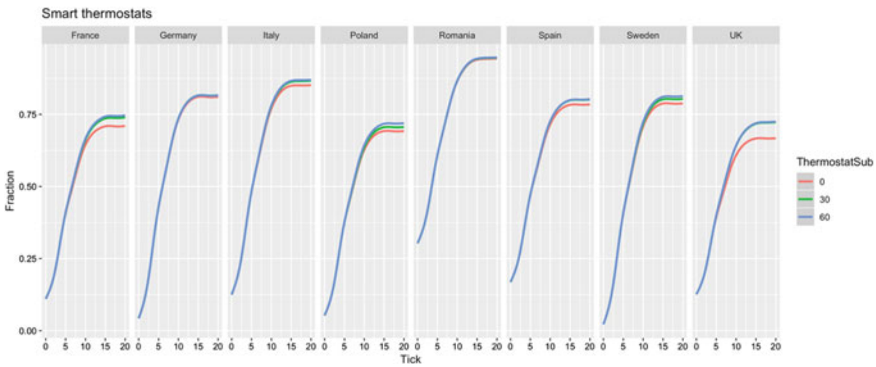

Fig. 45.2 Smart thermostat adoption in different countries, under different subsidy levels, over simulated time (in years)

Conclusions and Outlook

This paper presents an agent-based model of energy efficiency decisions in households, rooted in the theory of planned behavior and connected to a large survey of EU households, capturing 8 EU countries and utility functions for adoption decisions.

We have shown results on smart thermostats, illustrating differences between the effects of subsidies in 8 countries. The model is flexible and can be extended to include many other policies.

Future work includes a systematic analysis of this work in the context of other techno-economic models, simulations for other technologies, in particular fridges and heating systems, a detailed analysis of sensitivities and policy robustness and a detailed discussion of differences between countries. Furthermore, we expect to show a detailed policy analysis, with a wider variety of policies, also targeting at shops, which implies simulating more refined behavior of shops.

Acknowledgements This paper is supported by European Union's Horizon 2020 research and innovation programme under grant agreement No 723716, project CHEETAH (CHanging Energy Efficiency Technology Adoption by Households).

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