

Integrating discrete choice experiments and bottom-up energy demand models to investigate the long-term adoption of electrical appliances in response to energy efficiency policies

Tim Mandel¹, Heike Brugger¹, Marie-Charlotte Guetlein², Joachim Schleich^{1,2}

1: Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Straße 48, 76139 Karlsruhe, Germany
e-mail: tim.mandel@isi.fraunhofer.de; heike.brugger@isi.fraunhofer.de;
joachim.schleich@isi.fraunhofer.de
web: www.isi.fraunhofer.de

2: Grenoble Ecole de Management
12 rue Pierre Sémard, 38000 Grenoble, France
email: marie-charlotte.guetlein@grenoble-em.com; joachim.schleich@grenoble-em.com
web: www.en.grenoble-em.com

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1. Introduction

Energy efficiency policies in the European Union (EU) are subject to ongoing critical assessment with regard to their energy saving effects, cost-effectiveness, and distributional effects. Ex-ante evaluations of such policies are typically performed through energy-economy models [1]. However, these modelling approaches typically fail to account for heterogeneity in consumer preferences across technology variants (e.g. energy label classes), socioeconomic characteristics (e.g. income levels), or countries. For example, the PRIMES model used for the EU Reference Scenario 2016 applies a single implicit discount rate to simulate households' investment decisions for electrical appliances across all Member States and consumer types [2].

Addressing this research gap, this study integrates empirical findings on individual appliances adoption behaviour into a bottom-up energy demand model to simulate the long-term effects of major EU energy efficiency policies on the adoption of energy-efficient technologies. More specifically, employing representative surveys across ca. 4,500 households in eight EU countries in combination with the bottom-up energy demand model FORECAST, we analyse the impact of minimum energy performance standards (MEPS), labelling, and rebates on the diffusion of white appliances by energy label class and on energy demand in the EU-28 until 2030. White appliances currently account for approximately 40 percent of the EU's residential electricity use [3].

2. Methodology

Our methodology consists of two major elements. First, demographically representative surveys were carried out in eight EU Member Statesⁱ to empirically analyse factors influencing individual decision-making and the response of households to different policy instruments. The survey included a stated preference discrete choice experiment (DCE) on hypothetical technology adoption of refrigerators. In these DCEs, participants were asked to make a series of choices between different refrigerator purchase options. These options differed by energy label, size (volume), warranty length, customer review ratings, purchase price and availability of rebates for top-rated refrigerators. In addition to the DCE, the survey included items on socio-economic characteristics, attitudes, and household characteristics – including income, family size, and environmental preferences.

Second, the empirical findings from the DCE are implemented in the bottom-up vintage stock model FORECAST [4,5] to analyse the impact of the households' decision criteria and of policy instruments on the long-term diffusion of white appliances and on energy demand. Results from estimating the DCE via mixed-logit models [6] are used to parameterise the utility functions in FORECAST. Since our specification of the mixed-logit models allowed respondent valuation of technology attributes (e.g. energy label) to vary by household characteristics (e.g. income levels) and countries, these utility functions account for substantial heterogeneity across consumers (by household income, family size and environmental preferences). The logit specification of the latent utility function [7] is then used to calculate annual market shares (sales) per label class. To transfer the findings for refrigerators to other white appliances (e.g. washing machines), we assumed the estimated implicit discount rates [8] to be the same across white appliances per country. Likewise, to transfer the findings to the 20 EU countries not included in the sample of our survey, we conducted a cluster analysis [9] based on countries' similarity in socio-economic characteristics.

Important exogenous factors affecting the outcomes of our policy simulations include techno-economic variables (e.g. characteristics of technologies available, electricity prices) and policy variables (e.g. design of minimum energy performance standards). Our simulations compare a business-as-usual scenario (essentially comprising of current Ecodesign and labelling legislation) with a new policies scenario (essentially tightened MEPS combined with rebates for low-income households). In all scenarios, the framework conditions (population, electricity prices, etc.) are based on the EU Reference Scenario [2] and kept the same.

ⁱ The selected countries are France, Germany, Italy, Poland, Romania, Spain, Sweden, and the United Kingdom . They account for about 74% of the EU population [11]. In each country, participants were selected via quota sampling to be representative in terms of gender, age, income, and regional population dispersion. The survey was fielded in July and August 2018. The total sample size is $n = 4557$, with individual sample sizes ranging from 415 (Italy) to 599 (Sweden). Note that at the time the survey was implemented, the United Kingdom was still part of the European Union.

3. Results and Findings

Findings from the DCE generally suggest that participants dislike higher purchase prices of refrigerators, value rebates, and prefer appliances with better energy labels, larger volumes, longer warranties, and higher customer ratings [10]. These valuations are found to differ by household characteristics (income, household size, environmental preferences) and countries.

Embedded in the FORECAST model, the DCE results provide an empirical foundation for the scenario-specific simulations of the diffusion of white appliances in the EU in response to different policy instruments by 2030. Principal model outputs include yearly market shares (sales) and stock dynamics disaggregated by appliance technology (refrigerators, freezers, washing machines, dryers, dishwashers), energy label (A+++, A++, etc.), and consumer group (eight permutations of income level, family size and environmental preferences). Aggregated indicators include final energy demand and total cost of ownership (investment, maintenance, electricity costs). Figure 1 demonstrates how different policies affect long-term stock development of all white appliances from 2015 until 2030. Compared with the business-as-usual scenario, stricter MEPS combined with rebates, disbursed to low-income households, can clearly boost the adoption efficient household appliances. The former scenario is projected to entail a 20.4% (34.9 TWh) reduction in final energy demand in 2030 (compared to 2015 levels), while the latter scenario generates savings of 29.9% (51.0 TWh) in the same timeframe.

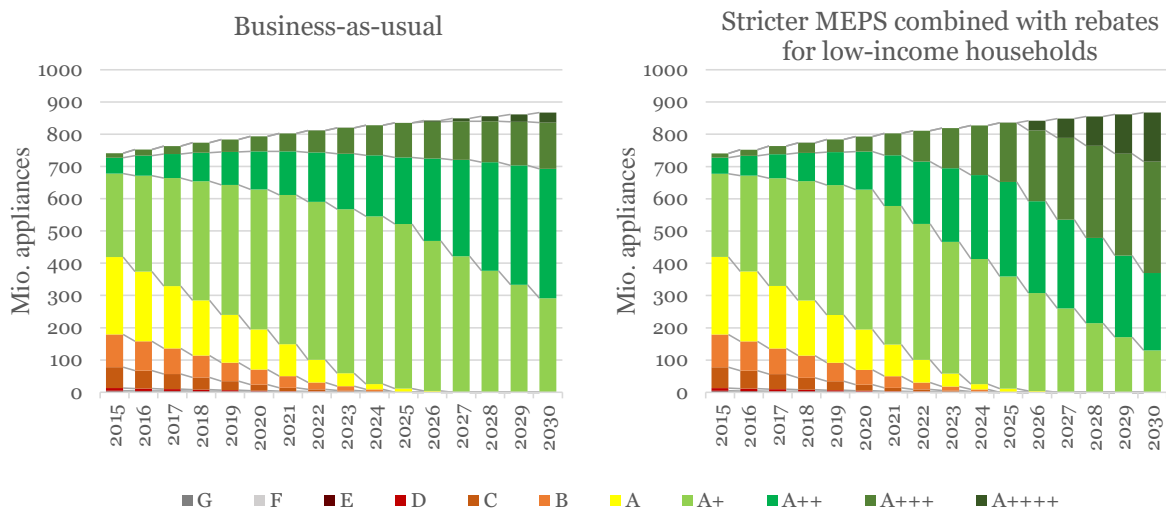


Figure 1. Stock development of white appliances in the EU-28 by energy label, 2015–2030.

While our findings underscore the significance of the EU's Ecodesign and Labelling legislation, they also indicate unwanted distributional effects for some countries in the case of stricter regulation, which should be considered in policy design. We conclude that, by coupling empirical data on individual appliance adoption with a bottom-up energy model, our approach provides robust insights into households' responses to energy efficiency policies and into long-term implications for energy demand.

Methodological limitations of the approach include the projection of cross-sectional survey data to future years (not accounting for prospective changes in consumer preferences), as well as no consideration of direct rebound effects (i.e., consumers increasing appliance use in response to achieved cost savings). In turn, our approach illustrates the benefits of distinguishing household response to policies (and technology features) by socio-economic group when assessing the effects of energy efficiency policies in the residential sector. This paper can only provide a sketch of potential applications. The empirical findings from the DCEs may also be integrated in other types of models (e.g. agent-based models). Finally, future research could expand this approach to other end-use technologies.

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