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How effective are EU minimum energy performance standards and energy labels for cold appliances?

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Abstract

In most countries, minimum energy performance standards (MEPS) and energy labels are the key policies to accelerate the diffusion of energy-efficient appliances and to help meet energy efficiency and climate policy targets. This paper estimates country-specific multivariate econometric models for eight EU countries over the period of 2007 to 2017 to evaluate the combined effects of changes in the MEPS and the energy labels entering into force in the EU in 2010 and 2011. The findings suggest that these policies increased the market share of cold appliances (refrigerators and fridge-freezer combinations) with an energy label of A+ and better between about 15 and 38 percentage points. For these appliances, autonomous developments (captured through a time trend) are estimated to range between 5 and 10 percentage points per year. Thus, failure to account for autonomous developments would have resulted in substantially overestimating the combined effects of MEPS and energy label policies in the EU. The findings further imply that policy evaluations should allow for policy effectiveness and autonomous developments to differ across countries.

Key words: energy efficiency; energy labelling; minimum energy performance standards; policy evaluation

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1 Introduction

Household appliances and lighting are responsible for about 60 percent of total European Union (EU) residential end-use electricity consumption (Eurostat, 2019). Refrigerators and freezers alone account for about 86 TWh per year, corresponding to about 11 percent of residential electricity consumption (VHK et al., 2016). Therefore, improving the energy performance of household appliances is crucial for achieving energy savings and climate policy targets in the EU and beyond. In particular, the Energy Efficiency Directive 2012/27/EU (EU, 2012) requires the EU to reduce primary and final energy consumption by 20 percent within 2020 (compared to a counterfactual projected primary and final energy consumption in 2020). Likewise, as part of the EU 2030 climate and energy framework, the Directive 2018/2002 (EU, 2018) foresees a reduction in EU primary and final energy consumption of at least 32.5 percent by 2030.

To accelerate the diffusion of energy-efficient appliances, the EU and other countries have long relied on minimum energy performance standards (MEPS) and energy labels. MEPS remove the worst energy performing appliances from the market. Limiting product availability in this way is believed to prevent consumers from purchasing products that may have lower purchasing costs but higher costs of total ownership than more energy-efficient products. By setting performance requirements, MEPS address bounded rationality on the side of appliance purchasers (Gillingham et al., 2009), but they may also limit product choice. MEPS are often combined with so-called 'comparative energy labels'[1], which may help overcome barriers related to information and search costs or bounded rationality (e.g. Sorrell et al., 2004). Labelling schemes are meant to make consumers aware of the relative energy efficiency of appliances through the provision of observable, uniform, and credible information (e.g. Truffer et al., 2001). So-called 'comparative energy labels' typically show a rating of the appliances, which is based on energy efficiency classes, along with expected energy use in kWh/year. MEPS eliminate the worst performing products from the market, and labelling schemes help consumers to make more informed choices.

1 'Comparative energy labels' allow consumers to judge the energy efficiency (or energy consumption) of the product in question using relative rankings of all appliances that have a label in the given appliance class.

Therefore, both MEPS and labelling schemes are termed 'market pull' policies (e.g. EC, 2009a).

In the EU, 28 product groups are currently covered by MEPS through the Ecodesign Directive 2009/125/EC (EC, 2009b) and 16 product groups are covered by mandatory energy labels though Regulation (EU) 2017/1369 (DG ENER, 2020).[2] These policies are projected to result in savings of 6700 PJ of primary energy by 2020, which corresponds to 19 percent saving compared to a reference scenario (Ecofys, 2014). Mandel et al. (2020) estimate MEPS and labels to lower final energy demand for refrigerators by at least 42 percent by 2030, thus contributing substantially to the EU 2030 energy efficiency targets set in Directive 2018/2002 (EU, 2018). MEPS and energy labels are therefore considered pillars of the EU's strategy to achieve its energy efficiency and climate policy targets. Outside of the EU, 557 MEPS and 589 comparative energy labels had been implemented or proposed by 2013 (EES, 2014).

In this paper, we evaluate the combined effects of the tightening of the MEPS in 2010 and the update of the energy labels in 2011 in the EU on the market shares of cold appliances (i.e. refrigerators and fridge-freezer combinations) in the top energy efficiency classes. To do so, we employ econometric methods accounting for the counterfactual development of these market shares, taking into account autonomous effects, i.e. those market developments that would have taken place in the absence of the policy because of technological progress or changes in behavioral and socioeconomic factors, for example. Despite their prevalence, only a few studies such as Bjerregaard and Møller (2019) have used econometric analyses to evaluate the effects of energy labels using actual appliance sales data. Our analyses rely on unique and original market data from 2007 to 2017 for eight EU countries (France, Germany, Italy, Poland, Romania, Sweden, Spain, and the United Kingdom), allowing for a comparison of policy effectiveness across these countries. These countries account for about three quarters of the EU final energy consumption in households, greenhouse gas (GHG) emissions and population (Eurostat, 2020). Furthermore, they cover a large geographic, cultural and economic variety of EU countries.

We organize the remainder of the paper as follows. In section 2, we provide a historic account of the relevant EU regulation on MEPS and energy labels. In

2 MEPS and energy labels are usually used in a complementary way (e.g. for consumer products). Some industrial or business-to-business products, however, are only addressed by MEPS.

section 3, we survey the empirical literature evaluating MEPS and energy labels for household appliances. In section 4, we present the empirical methodology, including the statistical-econometric model and the data set. In section 5, we report the findings, which are then further discussed in section 6. In the final section, we then summarize the key results, derive insights for policymaking, and point to needs for future research.

List of abbreviations

BAU	Business as usual
CE	Consumer electronics
DCE	Discrete Choice Experiment
EC	European Commission
EEI	Energy efficiency index
EU	European Union
GHG	Greenhouse gas
ICT	Information and communication technologies
KWh	Kilowatt hour
MEPS	Minimum energy performance standards
OLS	Ordinary Least Squares
UK	United Kingdom
WTP	Willingness to pay

2 EU regulation on energy performance of household appliances

The EU has a long tradition of setting MEPS and mandating energy labels for appliances. Both types of regulation have co-existed since the mid-1990s in all EU Member States.

As early as 1992, the EU ’Labelling Directive’ (EEC, 1992) required retail stores to furnish certain household appliances with comparative energy labels at the point of sale. The label provides standardized information on electricity use. Initially, seven energy efficiency classes were visualized by horizontal bars of different colors and length. These bars ranged from the green class-A label (best energy performance) to the red class-G label (worst energy performance). The EU published implementing directives for refrigerators, freezers and their combinations in 1994 (94/2/EC) (EC, 1994), for washing machines in 1995

(95/12/EC) (EC, 1995), and for dishwashers in 1997 (97/17/EC) (EC, 1997). Subsequently, the EU revised its regulation on MEPS and energy labels regularly to keep up with technological progress and market developments. Figure 1 illustrates these changes. The energy efficiency classes A+++ to G (indicated through their characteristic colors) as well as the MEPS (bold black line) are depicted in the metric of the Energy Efficiency Index (EEI).[3] A lower EEI reflects a better energy efficiency performance. The MEPS and the energy efficiency class are shown in relation to the EEI; the calculation of the EEI did not change during the period covered by this study.

Directive 2003/66/EC (EC, 2003) of 2003 introduced two additional energy efficiency classes, A+ and A++, to account for the large differences in energy efficiency between appliances in the highest class, which evolved due to major technological improvements. Those two classes were depicted on the label as black letters on an arrow next to the horizontal bar for the A-class, but without a distinct color. In 2010, Regulation (EU) 1060/2010 (EU, 2010) introduced an additional energy efficiency class A+++. Based on this regulation, from 2011 onwards, the three efficiency classes A+, A++ and A+++ were separately depicted on the label, now split into different shades of green. At the same time, energy efficiency classes were rescaled with new EEI requirements. This change became effective by the end of 2011. Essentially, our empirical analysis estimates the effectiveness of this change in labelling regulations (together with changes in the MEPS). In the same regulation, a tightening of the threshold for

3 The EEI for household refrigerating appliances is defined as the ratio between the measured energy consumption of the tested product and the calculated energy consumption of a reference appliance delivering the same energy service. It is calculated as follows (EC 643/2009) (EC, 2009c):

$$EEI = \frac{AE_C}{SAE_C} \times 100$$

where:

AE_C = Annual Energy Consumption of the household refrigerating appliance

SAE_C = Standard Annual Energy Consumption of the household refrigerating appliance.

SAEc is calculated according to a formula considering the characteristics of the appliance: category (e.g. upright freezer), volume and temperature of the different compartments and some correction factors according to the climate class, whether the appliance is built-in or free-standing, and whether it comes with frost-free or chill compartment features (EC, 1994).

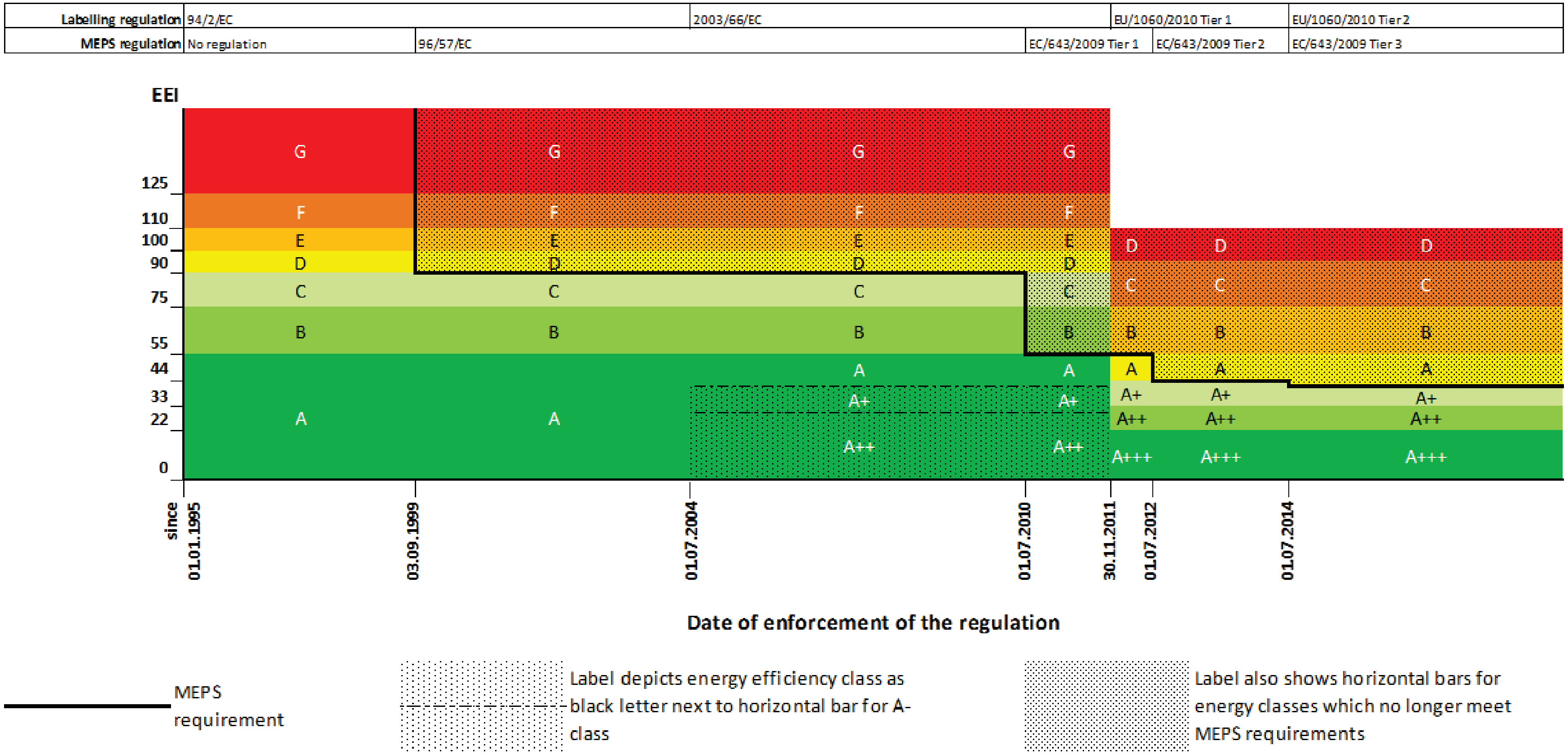
A+ refrigerators and freezers was prescribed, which eventually was implemented in 2014.[4]

The MEPS legislation was developed in parallel to the energy labelling legislation (see the so-called tiers or 'steps' in the black line in Figure 1). In 1996, the EU introduced MEPS (Directive 96/57/EC) (EC, 1996) (becoming effective in October 1999), which essentially prohibited manufacturers and importers from selling new refrigerators and fridge-freezer combinations in the energy efficiency classes D to G and most freezers in classes E to G. The MEPS were further tightened in 2009 by Regulation EC/643/2009 (European Commission, 2009c), which was implemented subsequently in the years 2010, 2012 and 2014. Yet, the label continued to show the horizontal bars of energy classes which were banned because the underlying EEI no longer met the requirements of the MEPS.

After 2010, appliances lower than class ‘A’ were technically banned from the market, and after 2012 appliances in class ‘A’ were banned. But in practice, some class ‘A’ appliances and lower were still sold in most of the EU countries after these deadlines. The reasons include non-compliance with the regulation (e.g. selling of less efficient appliances that were still in the stocks of sellers) and faulty labelling (SEVEn et al., 2013).

4 As of 2014, all refrigerators and freezers placed on the market had a green energy class (see Figure 1). This may have reduced the effectiveness of the label, because consumers may have erroneously interpreted an A+ label as a top energy efficiency rating. In response, regulation (EU) 2017/1369 (EU, 2017) re-introduced the A – G label. The new label for refrigerating appliances applies from 1 November 2020 onwards (c.f. regulation (EU) 2019/2016 (EU, 2019), which is after the time period covered in our empirical analysis).

Figure 1: Overview of the EU MEPS and energy labelling requirements for household refrigerators and freezers



3 Literature review on studies evaluating the effectiveness of MEPS and energy labels

Table 1 provides an overview of empirical studies analysing the effectiveness of MEPS and energy labels, organized by the methodology employed and in ascending order of date of publication. Several studies involve descriptive analyses of the EEI and market shares of new appliances sold, relying on observed historic market data. Comparing the EEI and the label class of newly sold appliances over time, they typically find MEPS and labels to have been effective. These ex-post evaluation studies, however, typically do not adequately take into account the counterfactual development on the supply and demand sides. On the supply side, autonomous technological progress is likely to have resulted in energy efficiency improvements in the absence of MEPS and labels. For product categories whose technological progress is fast, such as consumer electronics (CE) and information and communication technologies (ICT), Siderius (2014) highlights the need to shorten the formal process of setting and adjusting MEPS. Otherwise, the MEPS may not be effective by the time they come into force. Similarly, on the demand side, changes in behavioral and socioeconomic factors may also have resulted in higher market shares of more efficient appliances.

Most empirical studies employed stated preferences discrete choice experiments (DCEs) to analyze the effectiveness of energy labels. Through online household surveys, these studies ask participants to make hypothetical choices over different appliances which vary in terms of their attributes (including energy labels). DCEs also allow estimating participants' willingness-to-pay (WTP) for these attributes. DCEs may be used to simulate the effects of existing labels or of labels providing alternative information to existing labels. Most DCE-based studies find energy labels to be effective. DCEs allow analyzing whether the effectiveness of labels differs by the type of information provided on the label, by label scales, or by participant socio-economic characteristics or attitudes, or by countries. A major drawback, however, is their hypothetical nature because survey participants are not in an actual purchase situation. Also, for practical reasons, the appliances shown in the choice experiments cannot reflect the full variety of appliances available on the market. For these reasons, external validity of findings from DCEs may be low.

In comparison, econometric analyses rely on observed market data or on household surveys asking participants to report their past appliance purchase decisions. A variable indicating effectiveness is regressed on a set of 'explanatory' variables, which includes policy indicators and other variables potentially affecting effectiveness. This allows distinguishing the impact of the policy from other factors such as autonomous developments. However, arguably for lack of data, few studies have so far used econometric methods to evaluate MEPS or energy labels. They all find these policies to have been effective. Our paper adds to the emerging literature relying on econometric methods but differs from the existing studies. In comparison to Mills and Schleich (2014) and Huse et al. (2020), our data involves aggregate market data on observed purchasing decisions rather than stated individual adoption decisions. To evaluate the effects of MEPS and labels, our analysis uses a direct indicator of policy effectiveness, i.e. sales shares of top-rated appliances, rather than an indirect indicator like energy demand, as used by Filippini et al. (2016). Our approach is closest to that of Bjerregaard and Møller (2019) in terms of appliances, time frame, and type of data, but includes multiple countries, and uses annual rather than monthly sales data.

Finally, several studies use energy-engineering based bottom-up stock models to assess the effects of MEPS and energy labels on energy demand and GHG emissions. While studies employing descriptive statistics or econometric methods allow for ex-post evaluations of policies, stock-models are typically used to perform ex-ante assessments of policies which may range several decades into the future. To do so, they rely on historical developments, a current distribution of appliances and a (cost-based) function of adapting new appliances over time. In these models, MEPS alter the options of appliances available for adoption and labels alter the likelihood of adopting a particular appliance available on the market in a pre-specified manner. The findings from stock models all find MEPS and energy labels to be effective policies for decreasing energy consumption and GHG emissions of household appliances.

To summarize, the empirical literature evaluating the effectiveness of MEPS and energy labels typically finds these policies to accelerate the adoption of more efficient appliances. In addition, policy effectiveness may differ by technologies and countries. Studies on MEPS mostly rely on market data, while analyses of energy labels involve both market data and hypothetical decisions on appliance choice. In most studies, identification of policy effectiveness relies on a before-after comparison of the variable of interest such as the EEI or the sales shares of top-labelled appliances. Only few studies explicitly controlled for autonomous changes in the appliance market. Finally, when changes in MEPS and energy labels are implemented jointly or with short lag times, it may be difficult to disentangle the individual contribution of each policy to the observed changes in the indicators of policy effectiveness.

Table 1: Literature overview

Authors	Policy	Appliance type	Country	Time frame	Indicator of effectiveness	Methodology	Main findings
Descriptive statistics							
Schiellerup (2002)	MEPS	Cold Appli-ances	UK	1995-2000	EEI, market shares and specif-ic energy cons umption of appliances sold	Descriptive analysis of market data	MEPS reduced the energy consumption sub-stantially, provide financial savings and lead to a long-term transformation of the market
Lane et al. (2007)	MEPS, labels	Refrigera-tors	UK / Australia	1995-2006	Specific ener-gy consump-tion of appli-ances sold	Descriptive analysis of market data	Both policies have realized significant energy consumption savings, and are very cost-effective policy instruments.
Bertoldi et al. (2016)	Labels	White Ap-pliances	EU	2010-2014	Sales of appli-ances in high-est efficiency class	Descriptive analysis of market data	Steady increase of sales of models in top ener-gy label classes reflects effectiveness of energy label
Discrete choice experiments							
Sammer and Wüstenha-gen (2006)	Label	Washing machines	Switzer-land	2004	WTP for appli-ance with bet-ter energy rating	Multinomial logit model	WTP higher for appliances with better rating

Authors	Policy	Appliance type	Country	Time frame	Indicator of effectiveness	Methodology	Main findings
Shen and Saijo (2009)	Label	Air conditioners, refrigerators	China (Shanghai)	2006	WTP for appliance with better energy rating	Latent class and multinomial logit models	WTP higher for appliances with better rating; additional WTP for better rated refrigerators higher than for better rated air conditioners
Ward et al. (2011)	Label	Refrigerators	United States	2009	WTP for appliance with better energy rating	Conditional and mixed logit models	WTP higher for appliances with better rating;
Heinzle and Wüstenhagen (2012)	Label	TVs	Germany	2009	WTP for appliance with better energy rating	Hierarchical Bayes estimation	Higher preference for appliances with better rating; old EU label scale (A to G) more effective than new EU label scale (A+++ to D) in place since 2011
Newell and Siikamäki (2014)	Label	Water heaters	United States	2011	WTP for appliance with better energy rating	Multinomial logit model	WTP higher for appliances with better rating; showing annual operating costs on the label is more effective than showing kWh or CO_2 emissions
Davis and Metcalf (2016)	Label	Air conditioners	United States	2013	Preference for appliance with better energy rating	Conditional logit and regression models	Higher preference for appliances with better rating; showing operating cost information based on state-level usage and prices (rather than national usage and prices) improves welfare
Li et al. (2016)	Label	Refrigerator	United States	2009	WTP for appliance with better energy rating	Mixed logit model	WTP higher for appliances with better rating; offering rebates may lead to lower WTP for appliances with better ratings because rebates may be interpreted as signaling lower quality

Authors	Policy	Appliance type	Country	Time frame	Indicator of effectiveness	Methodology	Main findings
Zhou and Bukenya (2016)	Label	Air conditioners	China (Nanjing)	2013	WTP for appliance with better energy rating	Multinomial and mixed logit models	WTP higher for appliances with better rating
Andor et al. (2019)	Label	Refrigerators	Germany	2017	WTP for appliance with better energy rating	Binary choice, and multiple price list experiments, OLS	WTP higher for appliances with better rating; additional WTP higher for individuals with higher cognitive reflection
Guetlein et al. (2019)	Label	Refrigerators	8 EU countries	2018	WTP for appliance with better energy rating	Mixed logit models	WTP higher for appliances with better rating; additional WTP varies by income, age, and country, and is higher for more energy literate individuals;
Andor et al. (2020)	Label	Refrigerators	Germany	2015	WTP for appliance with better energy rating	Linear probability models	WTP higher for appliances with better rating; WTP is higher if annual energy cost information is shown on label
Faure et al. (2020)	Label	Refrigerators	Germany	2018	Preference for appliance with better energy rating	Mixed logit models	Higher preference for appliances with better rating; rescaled EU label (A to G) in place since 2011 more effective than old label scale (A+++ to D)
Zha et al. (2020)	Label	Refrigerators, washing machines	China	2017	WTP for appliance with better energy rating	Latent class models	Higher WTP for appliances with better rating; higher additional WTP for efficient refrigerators than for efficient washing machines

Authors	Policy	Appliance type	Country	Time frame	Indicator of effectiveness	Methodology	Main findings
Jain et al. (2021)	Label	Refrigera-tors	India	2015	WTP for appli-ance with bet-ter energy rating	Mixed logit models	Higher WTP for appliances with better rating; WTP is higher if annual energy cost information is shown on label
Econometric analy-ses							
Mills and Schleich (2014)	MEPS	Lamps	Germany	2010-2012	Household propensity to replace incan-descent lamp with energy-efficient lamp	Multinomial econometric methods based on stat-ed past bulb replacements	MEPs were effective (for bulb wattage levels banned in 2012)
Filippini et al. (2016)	MEPS, labels	Final ener-gy demand	EU-27	1996-2009	Residential electricity de-mand	Econometric stochastic frontier analy-sis using ob-served data	MEPS lower energy demand; no evidence that energy labels are effective
Bjerre-gaard and Møller (2019)	Label	Cold appli-ances	Denmark	2005-2017	Sales of appli-ances rated A+ and higher	Time-series econometric analysis based on observed data	Label increased the sales of appliances rated A+ and higher by 55 percent in 2010 (an-nouncement) and by an additional 42 percent in 2011 (implementation)
Huse et al. (2020)	Label	Refrigera-tors	Brazil	1998-2005	Household propensity to purchase en-ergy-efficient appliance	Random coef-ficients logit model based on stated past purchases	Label increased mean valuation of energy costs and energy efficiency of appliances but did not necessarily decrease overall energy consumption.

Authors	Policy	Appliance type	Country	Time frame	Indicator of effectiveness	Methodology	Main findings
Bottom-up stock models							
Sanchez et al. (2008)	Label	Various energy-consuming products	USA	1993-2025	Labelled units sold due to program	Bottom-up sales model	Significant decrease in energy consumption and emissions through the label; savings are highest for office equipment.
Yilmaz et al. (2019)	MEPS, labels	White Goods	Switzer-land	2015-2035	Total energy and emission savings	Bottom-up technology stock model	MEPS and labels significantly contribute to achieving energy and CO_2-emissions reduction targets
Boyano and Moons (2020)	MEPS, labels	Dishwash-ers	EU-28	2020-2030	Total energy and emission savings	Bottom-up technology stock model	Energy savings occur even in the BAU scenar-io; modifications in both policies can further accelerate adoption of energy-efficient appli-ances
Mandel et al. (2020)	MEPS, labels	Refrigera-tors	EU-28	2008-2030	Total energy and emission savings	Bottom-up technology stock model	Labels and MEPS lead to significant future energy savings but may have undesired distri-butional effects

4 Methodology

To evaluate the combined effects of the changes in the MEPS and the energy labels implemented in EU member states in 2010 and 2011, we employ data on the annual sales of cold appliances for eight EU countries over the period of eleven years. Data were analyzed using descriptive and graphical analysis, and multivariate econometric methods. In this section, we first describe the data and then the econometric model.

4.1 Data

Data on refrigerators and fridge-freezer combinations were acquired from the Gesellschaft für Konsumforschung (GfK), a leading market research institute with profound knowledge of the major domestic appliances markets in Europe. This data included annual information (2007-2017) on the number of units sold, the value of these sales expressed in the national currency, and information on the energy efficiency class (A/A+/A++/A+++ or "others" (i.e. class B or lower)) and the product category (two door fridge-freezer combinations with freezer on top (2DFTOP), two door fridge-freezer combinations with freezer at the bottom (2DFBTM), one-door refrigerators (1D), table-top refrigerators (TTOP), fridge-freezer combinations with three doors or more (3DPLUS), and side-by-side fridge-freezer combinations (SBS)).

Because our sample ranges over eleven years and includes six product categories, we have 66 observations available for each energy efficiency class in each country.

4.2 Econometric model

Our methodology allows estimating the combined effects of introducing MEPS in 2010 and updated labels in 2011 on the share of sales per energy efficiency class. Specifically, we use the change in market shares of different energy efficiency classes for new appliance purchases as the dependent variable, thereby distinguishing six product categories, i.e. 2DFTOP, 2DFBTM, 1D, TTOP, 3DPLUS, and SBS. Our empirical analysis distinguishes three groups of energy efficiency classes. Following Bjerregaard and Møller (2019), the first group is termed '>A' and comprises of appliances labelled A+, A++ or A+++-rated appliances. The second group is composed of the energy efficiency class A. Lastly, the third group, '<A', includes all energy efficiency classes which are lower than A.

We note that employing a difference-in-difference approach with (randomly assigned) treatment and control groups to estimate the policy effects is not feasible because once the policies are implemented, they govern the sales of all cold appliances in the EU. Thus, there is no country in the EU that may serve as a control group. Instead, we employ a before-after methodology, taking explicitly into account that some of the observed changes in market shares would have happened without the MEPS, i.e. because of changes over time in behavioral and socioeconomic factors such as preferences, tastes, attitudes, income, because of changes in prices, or because of technological progress. To control for this counterfactual autonomous development in the market shares of the different energy efficiency classes we include a time trend for each class and country. Employing a time trend to proxy the counterfactual is quite common in the literature (e.g. Wooldridge, 2007).

Specifically, our econometric approach involves estimating the following model:

$$(1)\, share_{tj}^{l} = \beta_{0j}^{l} + \beta_{1j}^{l} meps\&labels_{tj}^{l} + \beta_{2j}^{l} trend_{tj}^{l} + \gamma_{1j}^{l} 2DFTOP + \gamma_{1j}^{l} 1D + \gamma_{1j}^{l} TTOP + \gamma_{1j}^{l} 3DPLUS + \gamma_{1jSBS}^{l} + \varepsilon_{tj}^{l},$$

where l indexes the energy efficiency class (>A, A, <A), j indexes the country (FR, DE, IT, PL, RO, ES, SE, UK), and t indexes the year (2007 to 2017). The dependent variable $share_{tji}^{l}$ stands for the share of energy efficiency class *l* in the sales of a particular product category in year *t* in country *j*. We are particularly interested in the sign and magnitude of the coefficient β_1, which is associated with the policy dummy variable *meps&label* capturing the effects of the MEPS scheme and the changes in the energy label. Because the MEPS became effective in the middle of 2010, our annual data still includes sales of energy efficiency classes which took place before the ban. At the same time, because the new efficiency classes were known to manufacturers, retailers and customers prior to the actual implementation in late 2011, we allow for an announcement effect (similar to Bjerregaard and Møller, 2019). We therefore expect both policies to be effective in 2011 and accordingly set the dummy *meps&label* equal to one from 2011 on. Table 2 summarizes the description of the variables used in the econometric analysis. The effects of *meps&labels* on the share of cold appliances is allowed to differ by energy efficiency class and country, but not across product groups. Equation (1) includes the variable *trend* to capture autonomous effects. Finally, to control for the effects of product cate-

gories, equation (1) includes five product category dummy variables, i.e. 2DFTOP, 1D, TTOP, 3DPLUS, and SBS. To avoid perfect collinearity, equation (1) does not include a dummy for the product category 2DFBTM, which serves as the base category for the other five product categories. As we show in section 5.1, 2DFBTM are the best-selling new cold appliance in most countries included in our sample. For each product category and country, the coefficient γ_j^l therefore captures the difference in the market share of a particular product category compared to the base product category 2DFBTM. Finally, ε_{tj}^l stands for the usual error term. Because we estimate equation (1) for three energy efficiency classes and each of the eight countries, we ran a total of 24 regressions, employing Ordinary Least Squares (OLS) with robust standard errors. All analyses were performed with Stata.

Table 2: Description of variables

Label	Description
Dependent variable	
share	Share of a particular energy efficiency class in the sales of new cooling appliances of a particular product category
Covariates	
meps&label	Policy dummy = 1 from the year 2011 on
trend	Trend variable
2DFTOP	Product category dummy = 1, if two door fridge-freezer combinations with freezer on top
1D	Product category dummy = 1, if one-door refrigerators
TTOP	Product category dummy = 1, if table top refrigerators
3DPLUS	Product category dummy = 1, if fridge-freezer combinations with three doors or more
SBS	Product category dummy = 1, if side-by-side fridge-freezer combinations
2DFBTM	Product category dummy = 1, if two door fridge-freezer combinations with freezer at the bottom; base product category

5 Results

Before presenting the results of estimating equation (1), we first provide some descriptive and graphical analyses.

5.1 Descriptive and graphical analysis

Table 3 shows that for the period 2007 to 2017, cold appliances labelled >A accounted for the highest market share among the three energy efficiency classes, while cold appliances labelled <A accounted for the lowest share. This is not surprising as appliances labelled <A are officially banned since mid-2010. However, some sales of these lesser-efficient <A appliances are still observed due to false labelling and non-compliance. At the same time, there is substantial heterogeneity across countries. For example, the share of appliances labelled >A was highest in Germany (ca. 80 percent) and lowest in the UK (ca. 60 percent). In comparison, the UK had the highest share of appliances labelled A (ca. 39 percent), while Germany and Italy had the lowest shares (ca. 18 percent each). Finally, the share of appliances labelled <A was highest in Italy (ca. 5 percent) and lowest in Sweden (ca. 1 percent).

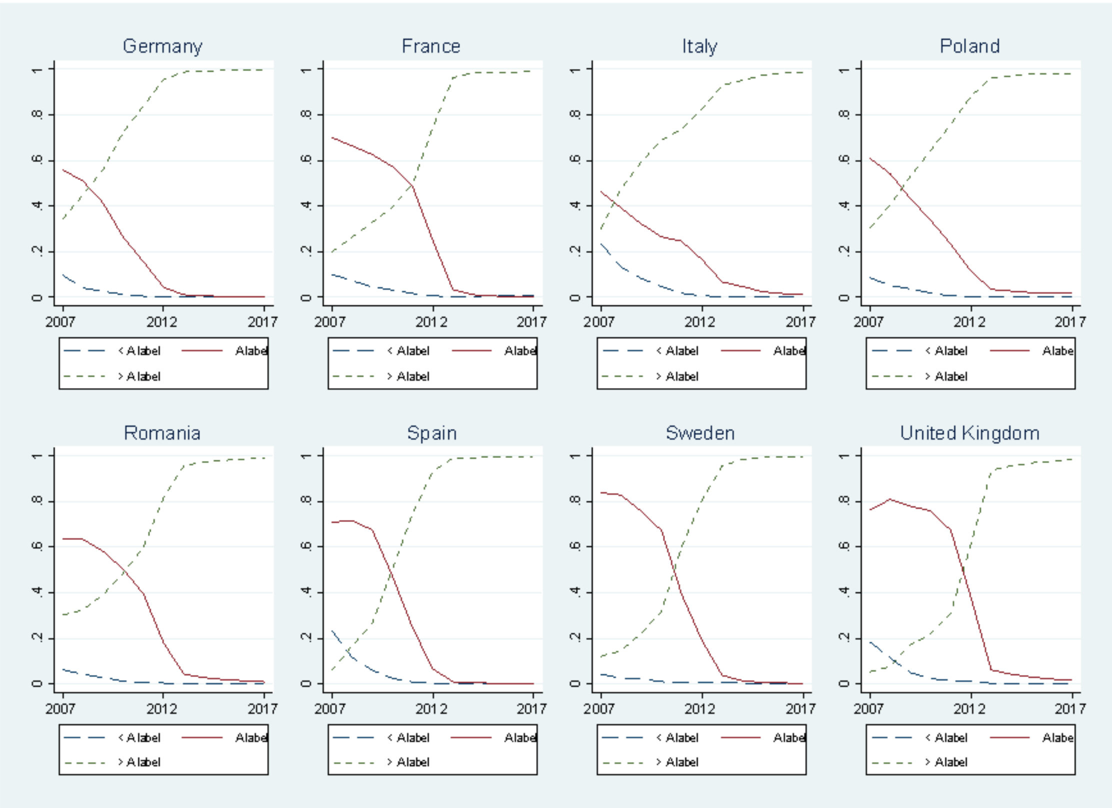
In most countries, the best-selling new cold appliance was a 2DFBTM. The market share of 2DFBTM ranged between ca. 33 percent in France and 75 percent in Poland. In Italy, the best-selling cold appliance was a 2DRFTOP. The share of >3D types was highest in Sweden (ca. 37 percent), while the share of TTOP types was highest in the UK (26 percent). For other cold appliances, the market shares were usually below 10 percent. In particular, in all countries, 1D refrigerators accounted for the lowest shares of typically below 1 percent.

Figure 2 displays the development of the market shares of new cold appliances by energy efficiency classes over time. In 2007, i.e. three years after the new energy efficiency classes A+ and A++ had been introduced, cold appliances labelled >A had gained a considerable market share of around 30 percent in Germany, Italy, Poland and Romania. In contrast, their market share was below 10 percent in Spain, and the UK. Clearly, in all countries, the shares of cold appliances labelled >A show an increasing trend in the years before the changes in MEPS (in 2010) and in labels in (2011) became effective, while the shares of cold appliances labelled A and <A showed a decreasing trend. Figure 2 illustrates that the distribution of the energy efficiency classes in the stock of cold appliances varied substantially across countries when the new MEPS and the new label scheme became effective.

Table 3: Average market shares of energy efficiency classes and product category across countries

	France	Germany	Italy	Poland	Romania	Spain	Sweden	UK
Energy efficiency class								
>A	0.6671	0.8039	0.7681	0.7636	0.7095	0.6945	0.6491	0.5697
A	0.3050	0.1791	0.1839	0.2171	0.2761	0.2643	0.3401	0.3935
<A	0.0279	0.0169	0.0482	0.0191	0.0143	0.0412	0.0108	0.0368
Product category								
2DFBTM	0.3298	0.3649	0.4237	0.7493	0.6080	0.6135	0.4633	0.5519
2DRFTOP	0.2708	0.0845	0.4314	0.0916	0.2835	0.2418	0.0337	0.0462
TTOP	0.1541	0.3619	0.0813	0.1044	0.0627	0.0648	0.0950	0.2559
1D	0.0145	0.0047	0.0071	0.0064	0.0013	0.0050	0.0050	0.0132
3DPLUS	0.1814	0.1537	0.0376	0.0183	0.0345	0.0462	0.3747	0.0629
SBS	0.0490	0.0302	0.0179	0.0299	0.0098	0.0285	0.0263	0.0689

Figure 2: Market shares of cold appliances by energy efficiency class over time



5.2 Econometric analysis

Results from estimating equation (1) appear in Table 4 for the shares of cold appliances labelled >A, in Table 5 for the shares of cold appliances labelled A, and in Table 6 for the shares of cold appliances labelled <A. P-values are reported in parentheses below the parameter estimates.

Of our prime interest are the coefficients associated with the policy variable *meps&label*, i.e. β_1 in equation (1). We first present the findings for the highest energy efficiency class. For cold appliances labelled >A, the coefficient is, as expected, positive in all eight countries. For the UK, the coefficient is just shy of being statistically significant at the 10 percent level. These findings provide evidence that combination of a change in the MEPS and the energy labels in 2010 and 2011 have led to an increase in the market share of appliances labelled >A in all countries. The magnitude of this effect, however, differs across countries. Comparing the point estimates for β_1 across countries, the strongest effects can be observed in Spain and Sweden, where these policies resulted in an increase of 38.4 and 32.9 percentage points respectively in the market share of appliances labelled >A over the period 2011 to 2017. For Poland and Romania, this increase amounts to about 22 percentage points, and for the remaining countries, it ranges between about 15 and 19 percentage points.

Table 6 suggests that the changes in the MEPS and label regulations in 2010 and 2011 have typically led to a decrease in the market share of appliances labelled A. The coefficient associated with *meps&label* is negative in all countries and statistically significant at conventional levels in all countries but the UK. The strongest effects can be observed in Spain and Sweden, where these policies resulted in a decrease of more than 30 percentage points in the market share of appliances labelled A. For the other countries in our sample, this effect is typically about half as strong as in Spain and Sweden.

Table 4: Results for cold appliances labelled >A

	France	Germany	Italy	Poland	Romania	Spain	Sweden	UK
meps&label	0.188***	0.165**	0.178***	0.225***	0.217**	0.384***	0.329***	0.152
	(0.006)	(0.014)	(0.000)	(0.000)	(0.011)	(0.000)	(0.001)	(0.107)
trend	0.075***	0.046***	0.051***	0.054***	0.079***	0.049***	0.077***	0.101***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
2DFTOP	-0.069	-0.144***	-0.068*	-0.058	-0.006	-0.073	-0.146**	-0.090
	(0.101)	(0.005)	(0.072)	(0.166)	(0.902)	(0.113)	(0.025)	(0.182)
1D	0.033	0.034	-0.023	0.025	-0.182***	0.020	0.040	-0.034
	(0.444)	(0.444)	(0.513)	(0.583)	(0.007)	(0.659)	(0.338)	(0.499)
TTOP	-0.128***	-0.079*	-0.233***	-0.232***	-0.246***	-0.036	-0.126**	-0.107*
	(0.008)	(0.057)	(0.000)	(0.000)	(0.000)	(0.379)	(0.022)	(0.060)
3DPLUS	-0.067	-0.032	-0.094**	-0.114**	-0.224***	0.060	-0.121*	-0.130**
	(0.177)	(0.586)	(0.020)	(0.042)	(0.003)	(0.192)	(0.075)	(0.037)
SBS	-0.050	-0.070	-0.037	-0.133**	-0.100**	-0.044	0.011	-0.008
	(0.235)	(0.292)	(0.484)	(0.011)	(0.023)	(0.298)	(0.797)	(0.872)
Constant	0.135***	0.462***	0.404***	0.332***	0.122***	0.177***	-0.017	-0.099**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.004)	(0.000)	(0.672)	(0.019)
N	66	66	66	66	66	66	66	66
R^2	0.903	0.768	0.883	0.861	0.875	0.919	0.891	0.887

*** p<0.01, ** p<0.05, * p<0.1

Table 5: Results for cold appliances labelled A

	France	Germany	Italy	Poland	Romania	Spain	Sweden	UK
meps+label	-0.163**	-0.151**	-0.136***	-0.188***	-0.187**	-0.329***	-0.313***	-0.121
	(0.017)	(0.019)	(0.003)	(0.004)	(0.039)	(0.000)	(0.003)	(0.239)
trend	-0.071***	-0.042***	-0.038***	-0.045***	-0.071***	-0.038***	-0.073***	-0.092***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
2DFTOP	0.045	0.109**	0.024	0.044	-0.001	0.036	0.144**	0.054
	(0.263)	(0.011)	(0.376)	(0.234)	(0.970)	(0.370)	(0.030)	(0.477)
1D	-0.041	-0.033	0.003	-0.042	0.098	-0.039	-0.035	0.019
	(0.322)	(0.399)	(0.897)	(0.224)	(0.205)	(0.231)	(0.379)	(0.710)
TTOP	0.094**	0.058	0.162***	0.119***	0.171***	-0.061	0.064	0.044
	(0.040)	(0.114)	(0.000)	(0.007)	(0.001)	(0.230)	(0.274)	(0.513)
3DPLUS	0.076	0.025	0.081**	0.091	0.224***	-0.048	0.121*	0.126*
	(0.129)	(0.664)	(0.028)	(0.178)	(0.003)	(0.193)	(0.084)	(0.064)
SBS	0.060	0.064	0.039	0.127**	0.102**	0.045	-0.008	0.016
	(0.165)	(0.304)	(0.414)	(0.020)	(0.017)	(0.298)	(0.864)	(0.750)
Constant	0.812***	0.496***	0.475***	0.589***	0.805***	0.697***	0.981***	1.008***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
N	66	66	66	66	66	66	66	66
R^2	0.888	0.764	0.827	0.767	0.814	0.888	0.874	0.825

*** p<0.01, ** p<0.05, * p<0.1

Table 6: Results for cold appliances labelled <A

	France	Germany	Italy	Poland	Romania	Spain	Sweden	UK
meps&label	-0.025***	-0.015	-0.042**	-0.037*	-0.030	-0.055**	-0.016	-0.031
	(0.004)	(0.111)	(0.049)	(0.078)	(0.157)	(0.031)	(0.112)	(0.101)
trend	-0.004**	-0.005**	-0.012***	-0.008**	-0.008	-0.011**	-0.003*	-0.009***
	(0.019)	(0.023)	(0.004)	(0.033)	(0.101)	(0.021)	(0.065)	(0.007)
2DFTOP	0.023***	0.035*	0.044**	0.014	0.008	0.038	0.002	0.036
	(0.003)	(0.066)	(0.034)	(0.307)	(0.595)	(0.105)	(0.614)	(0.122)
1D	0.009*	-0.001	0.020	0.017	0.084*	0.019	-0.005	0.015
	(0.087)	(0.896)	(0.230)	(0.293)	(0.094)	(0.391)	(0.427)	(0.236)
TTOP	0.035**	0.021**	0.071**	0.113***	0.075***	0.097**	0.062***	0.063**
	(0.020)	(0.024)	(0.042)	(0.004)	(0.007)	(0.040)	(0.001)	(0.024)
3DPLUS	-0.008	0.008	0.013	0.023	0.000	-0.012	-0.000	0.005
	(0.288)	(0.325)	(0.629)	(0.350)	(0.990)	(0.550)	(0.984)	(0.748)
SBS	-0.010	0.007	-0.002	0.007	-0.002	-0.001	-0.004	-0.008
	(0.148)	(0.529)	(0.928)	(0.660)	(0.913)	(0.954)	(0.546)	(0.571)
Constant	0.053***	0.042***	0.121***	0.078***	0.073**	0.126***	0.036***	0.091***
	(0.000)	(0.001)	(0.000)	(0.001)	(0.013)	(0.000)	(0.000)	(0.000)
N	66	66	66	66	66	66	66	66
R^2	0.592	0.411	0.516	0.480	0.346	0.492	0.552	0.493

*** p<0.01, ** p<0.05, * p<0.1

We now turn to the findings for the lowest energy efficiency class. For appliances labelled <A, the effects of the changes in the MEPS and energy labels on the market share are also negative in all countries. But for Germany, Romania, Sweden and the UK, the associated coefficient is just shy of being statistically significant at the 10 percent level. In all countries, the magnitude of the effect is much smaller than for appliances labelled A.

The point estimates for β_1 range between -1.5 percentage points in Germany, and -5.5 percentage points in Spain. Figure 3 further illustrates this point.

Finally, we note that, as expected, for each country, the changes in the market shares across energy efficiency classes in response to the policy changes for MEPS and energy labels add up to one.

Next, the results in Table 2, Table 3, and Table 4 for the *trend* variable, which reflects autonomous developments (i.e. β_2 in equation (1)), suggest that the market shares of cold appliances labelled >A would have grown while the shares of cold appliances labelled A and <A would also have declined had there been no tightening of the MEPS in 2010 and no changes in the energy labels and 2011. The coefficient associated with *trend* is, as expected, positive and

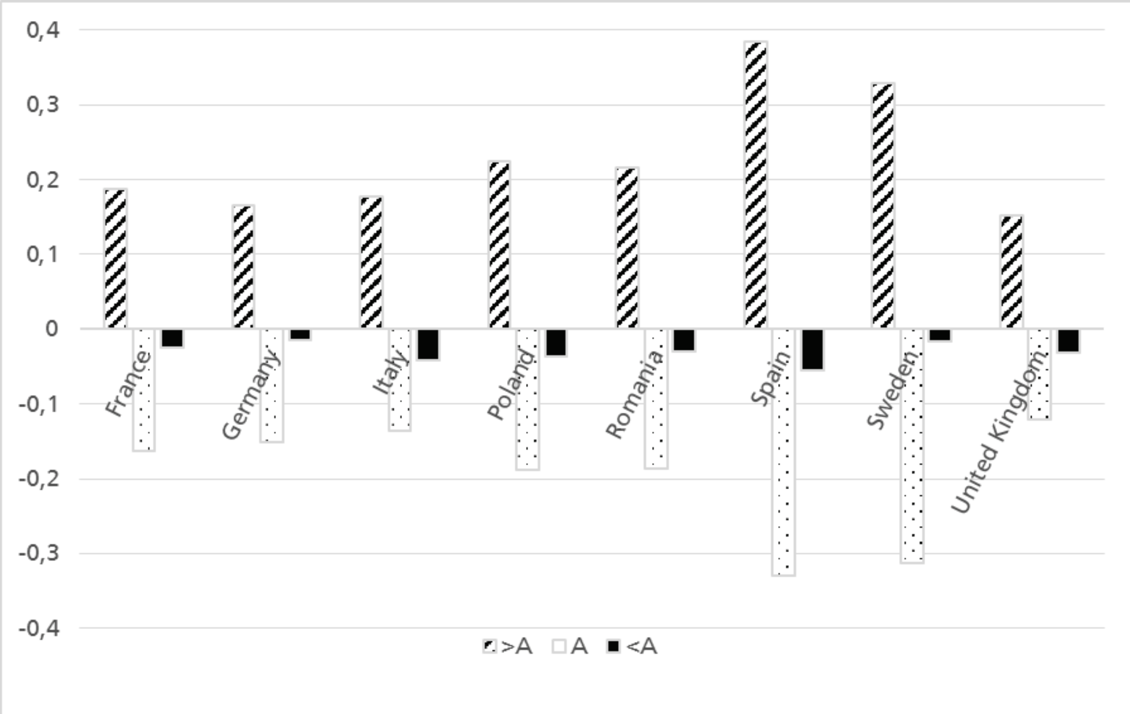
statistically significant at the 1 percent level in all eight countries. For example, in France the share of appliances labelled >A is estimated to grow on average by 7.5 percentage points per year between 2007 and 2017 because of autonomous developments. This trend effect on the share of cold appliances labelled >A generally differs across countries and ranges between ca. 5 percentage points in Germany, Italy, Poland, or Spain to about 10 percentage points in the UK.

For cold appliances labelled A and <A, the *trend* coefficient is negative and statistically significant at least at the 10 percent level in almost all countries.[5] The negative trend effect for cold appliances labelled A is particularly strong in the UK (ca. -9 percentage points). For cold appliances labelled <A, the trend effects are generally small if expressed in terms of changes in percentage points, not least because the market shares of cold appliances labelled <A are rather small.

Finally, the findings for the coefficients associated with the product category dummies suggest limited heterogeneity in the market shares of cooling appliances labelled A and <A across product categories. For cold appliances labelled >A though, the market shares of TTOP refrigerators are typically lower than for the base category, i.e. 2DFBTM fridge-freezer combinations. In contrast, for cold appliances labelled A and <A, the market shares of TTOP refrigerators tend to be higher than for the base category.

5 The only exception is <A in Romania, where the p-value is slightly above 10 percent.

Figure 3: Estimated effects of the EU MEPS and energy labels on the market shares of cold appliances by energy efficiency class



6 Discussion of results

The key result of our econometric analysis suggests that the changes in the regulation for MEPS and energy labels which came into effect in 2011 have generally increased the sales share of cold appliances labelled A+ and better, and lowered the sales share of cold appliances labelled A and <A in the eight EU countries included in our sample. These findings are qualitatively similar to previous empirical studies that conduct ex-post evaluations of MEPS and/or labels. Because these studies employed different methodologies and indicators, we cannot compare our findings in a quantitative sense, even for studies considering the same appliances as ours. For example, the study by Bjerregaard and Møller (2019), which is closest to ours in terms of appliances considered, methodology and time frame, analyzes the effects of labels change in the energy label for cold appliances in 2011 (EU/1060/2010; EU, 2010) on the sales *volumes* of cold appliances by energy class in Denmark. They find that the change of the label increased the sales of highly efficient appliances (A+ and higher) by 55 percent at the time of the announcement in 2010 and by an additional 42 percent when the labels were implemented in 2011. In comparison,

our study considers the combined effects of MEPS and labels on the sales *shares* by energy class. Also, Denmark is not included in our set of countries. While relying on a fundamentally different methodology, our findings qualitatively support the results of those descriptive analyses comparing the observed development of the average EEI or of new sales by energy class over time, or of DCE-analyses relying on hypothetical appliances choices. Naturally, the findings of our ex-post analyses cannot be compared with ex-ante simulations by bottom-up technology stock models. However, our findings may help parameterize the effects MEPS and energy labels and of autonomous trends in these models.

Our findings further suggest differences in the effectiveness of the changes in the regulations for MEPS and label across label classes. In particular, we generally observe the smallest quantitative impact on cold appliances labelled <A. This finding is little surprising, because cold appliances with an energy class < A were officially banned since mid-2010 (see Figure 1).

We also find policy effectiveness to vary substantially across countries. Particularly strong effects could be observed for Sweden and Spain and particularly weak effects for Germany. Differences in the composition of the appliance stock across countries may affect the effectiveness of MEPS and energy labels across countries (Michel et al., 2016). As shown in Figure 2, the share of cold appliances labelled >A before 2010 was relatively high in Germany and relatively low in Spain and Sweden. Thus, the remaining potential was larger in Spain than in Germany when the policies came into force in 2010 and 2011. The estimated differences of policy effectiveness across countries are likely to reflect differences in national policies promoting the diffusion of energy-efficient appliances such as information and awareness campaigns, rebates or tax breaks. Likewise, since electricity prices differ, financial incentives to adopt more energy efficiency appliances vary across countries. Pricing policies have also been shown to be more effective when applied in combination with other policies such as standards or labelling, as found by Newell et al. (1999). The estimated differences in policy effectiveness across countries may also be driven by differences in household responsiveness to policies. In the case of energy labels, responsiveness may be driven by energy literacy, which varies across countries (Guetlein et al., 2019). Likewise, there may be differences across countries related to acceptability of particular types of energy efficiency policy (Whitmarsh et al, 2019). Finally, Ecofys (2014) consider differences in the monitoring and enforcing of these regulations to explain differences in the transition of the appliance markets across EU countries.

Further, our findings for the trend variable suggest that the sales shares of energy-efficient cold appliances would have grown while the sales shares of non-efficient cold appliances would have declined had there been no tightening of the MEPS and changes in the energy labels. Thus, autonomous developments not specifically modelled in our analysis, which may be driven by technological progress, changes in individual preferences (e.g. environmental awareness), or economic factors (e.g. electricity or product prices) would also have contributed to a transition of the cold appliance market in those countries. Differences in these factors may also explain the estimated differences in the effects of the trend variable across countries.

7 Conclusion and policy implications

Our findings from estimating country-specific multivariate econometric models for eight EU countries over the period of 2007 to 2017 suggest that the changes in the MEPS and the energy labels entering into force in 2010 and 2011 increased the sales share of cold appliances with an energy label of A+ and better between about 15 and 38 percentage points. At the same time, these policies are estimated to have lowered the share of cold appliances labelled A between about 12 and 33 percentage points. Because the changes in the regulation for MEPS and energy labels came into effect around the same time, our empirical analysis does not allow disentangling the contribution of the MEPS and energy labels on the cold market transformation. Qualitatively, these results generally support earlier empirical analyses which employed databases and methodologies different from ours and found MEPS and energy labels to be effective.

We further find policy effectiveness to vary substantially across countries. These differences of policy effectiveness across countries may reflect differences in the distribution of cold appliances by energy class in the residential sector at the time the policies became effective, differences in national policies promoting the diffusion of energy-efficient appliances, and differences in individual energy or financial literacy or attitudes towards policies across countries.

Our findings further suggest that some transformation of the cold appliance market would have taken place without the combined changes in the EU regulation on MEPS and energy labels, for example because of technological progress or societal trends. For the countries included in our study we estimate these autonomous effects to range between 5 and 10 percentage points per year for the change in market shares of cold appliances labelled >A.

Our findings also have important policy implications. First, they suggest that the combination of MEPS and energy labels have transformed the markets of cold appliances for the countries included in our sample. But the effectiveness of these policies is likely to depend on country-specific factors such as national policies promoting energy-efficient appliances prior to and accompanying the policy change at EU level. Second, evaluations of MEPS and energy labelling policies should take into account autonomous effects when developing the counterfactual. In our context, these autonomous effects were estimated to be quite substantial. Thus, failure to account for autonomous effects may result in substantially overestimating policy effectiveness. In addition, our findings imply that policy evaluations should allow for autonomous effects to differ across countries.

Our analyses also come with some caveats. To reflect autonomous effects, our econometric analysis employed a simple time trend, which may be a rather crude measure only. Relying on longer time series of data, future research could try to more explicitly model these effects by including information on other support measures or electricity prices, for example. Similarly, market responses of manufacturers and retailers to these policies could be included, such as changes in appliance prices (e.g. Houde, 2018). Data and the timing of the implementation of MEPS and energy labels permitting, future research may also try to disentangle the individual contribution of these policies on the transformation of the appliance markets. While we found these policies to have increased the market shares of the most energy-efficient cold appliances, actual energy use may not follow suit. Because MEPS and energy labels are based on the EEI, higher shares of cold appliances labelled >A might be accompanied by a trend towards larger appliances, thus offsetting some of the improvements in energy efficiency on total energy use. In addition, appliance manufacturers have been found to offer appliances that bunch at the label requirement (Houde, 2018), and to misreport the self-certified EEI of their products (Goeschl, 2019). Thus, to more adequately assess the effects of MEPS and energy labels on energy use, changes in the decomposition of the appliance stock in terms of size and technical specifications would have to be considered. Including these factors in future empirical analyses should provide a more accurate account of the contribution of MEPS and energy labels to the transformation of the appliance markets.

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