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How Effective are Energy Labels? Evidence from the 2021 EU Reform

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Abstract: Energy labels are often used to promote the adoption of more energy-efficient domestic appliances. This paper provides evidence on the impact of the 2021 revision of the EU energy labeling regulation using product-level sales data on refrigerators in four European countries (Belgium, France, Germany, and Poland). We first document substantial cross-country differences in sales-weighted energy consumption, reflecting differences in product portfolios and consumer preferences. Controlling for product characteristics, average energy consumption declines by between 3.3% in France and 4.2% in Belgium following the reform. We subsequently estimate a product-level demand model that incorporates energy labels in utility either directly or through their associated 15-year electricity costs. The results indicate that consumers undervalue future energy costs under both labeling regimes, although the degree of undervaluation declines under the new labels. Counterfactual simulations suggest that the labeling reform generated only modest energy efficiency gains. Larger gains could be achieved through alternative policies: stricter minimum standards (banning the least efficient appliances) or fiscal incentives (a feebate scheme subsidizing efficient appliances while taxing inefficient ones).

Keywords: Energy Efficiency, EU Energy Label, Nested Logit

JEL codes: D12, L51, Q58

1 Introduction

In response to accelerating climate change, the European Union (EU) has committed to achieving carbon neutrality by mid-century. This objective is central to the European Green Deal, a comprehensive policy framework aimed at promoting cleaner energy, greater efficiency, and sustainable economic growth. A central element of this transition is improving the energy performance of products and buildings while addressing challenges such as energy poverty.

Energy efficiency plays a central role in the EU's decarbonization agenda. Global estimates suggest that improvements in end-use energy efficiency alone could reduce CO_2 emissions by up to 35% by 2050, even in the context of continued global economic growth. According to Eurostat, households in the EU accounted for approximately 26% of total final energy consumption in 2023. Within the residential sector, around 14.5% of energy use was attributable to lighting and appliances, while 77.6% was devoted to space and water heating. These figures emphasize the importance of promoting the adoption of energy-efficient technologies in the residential sector.

Two key instruments support the EU's approach to energy efficiency in consumer goods and industrial equipment: the Energy Labeling Regulation and the Ecodesign Directive. The former informs consumers through standardized efficiency labels, while the latter removes the least efficient products from the market by imposing minimum performance standards.

The New EU Energy Labeling Regulation, implemented in March 2021, aims to influence energy consumption, consumer choice, and environmental sustainability through both demand- and supply-side channels. On the demand side, it seeks to make energy efficiency information easier to understand and compare across products. On the supply side, it encourages manufacturers to develop more energy-efficient products. Together with the Ecodesign Directive, which establishes mandatory ecological requirements for energy-using products, it also facilitates the removal of inefficient products from the market.

Despite the central role of energy labels in EU policy, their effectiveness remains an empirical question. This paper addresses the following questions. Did the introduction of the new labeling regulation in 2021 reduce the energy consumption of household appliances sold in the EU? Did the regulation lead to a reallocation of sales toward more energy-efficient products? Do energy labels help consumers account for future energy costs when making purchase decisions? Are there differences across EU countries, and what explains them? Finally, what would be the impact of alternative regulatory or fiscal policies compared with informational measures? Specifically, we consider the possibility of banning the sale of inefficient refrigerators or implementing a feebate policy, which combines a subsidy ("rebate") for energy-efficient products and a tax ("fee") for energy-intensive ones.

We address these questions by analyzing changes in the annual energy consumption of refrigerators sold in four European countries—Belgium, France, Germany, and Poland—between 2019 and

2022. This period covers the introduction of the new EU energy labeling framework, established by Regulation (EU) 2017/1369 of 4 July 2017, which came into force on 1 March 2021. From that date, several product groups, including refrigerators, dishwashers, washing machines, and electronic displays, had to be sold with the new rescaled energy labels. We focus on refrigerators because they operate continuously, implying that energy consumption is largely determined at the time of purchase rather than through subsequent usage decisions.

The raw data reveal significant variation in the average sales-weighted energy consumption of refrigerators across these four countries, with substantially lower levels in Germany and Belgium due to differences in product portfolios and consumer purchasing behavior. In contrast, consumers in France and Poland tend to purchase less energy-efficient products. We generate an energy efficiency index for each country using a regression that controls for a broad range of refrigerator characteristics, as well as changes in the range and quantity of models purchased in each country over time. The differences in average energy efficiency across countries persist but become smaller, indicating substantial cross-country variation in the features of purchased products that affect their energy consumption. The energy efficiency indices for all countries show a steady decline after March 2021. Specifically, the average energy consumption of refrigerators between March 2021 and December 2022 decreased by 3.1% in France, 4.8% in Poland, 5.4% in Germany, and 7.3% in Belgium. After controlling for refrigerator characteristics that affect energy usage, the decline was 3.3% in France, 3.5% in Poland, 3.4% in Germany, and 4.2% in Belgium. However, we cannot attribute this decline to the new energy labels.

We subsequently estimate two specifications of a nested logit demand model for refrigerator purchases. The first demand specification is the most flexible and directly incorporates energy labels in consumer utility. We estimate consumers' willingness to pay (WTP) for energy labels relative to the least efficient baseline labels—A+ under the old regulation and G under the new regulation. Across all countries, consumers display systematically higher WTP for more energy-efficient labels, indicating that energy labels successfully convey information about product quality and energy performance. Our estimates suggest that consumers partially internalize future electricity costs when making refrigerator purchase decisions, but tend to undervalue them relative to the full magnitude of expected savings.

The second specification adds more structure. Instead of flexibly including energy label effects, it incorporates the expected 15-year cost of electricity consumption associated with each label.[1] The results indicate that consumers in France and Belgium substantially undervalue future electricity costs under both the old and new labeling regimes. The degree of undervaluation is lower in Germany and lowest (but still present) in Poland. Our results indicate that following the introduction of the new labels, the magnitude of this undervaluation decreases.

1. According to the European Environment Agency (EEA), the average lifespan of a refrigerator in 2023 was 13 years and 5 months, representing an increase of 1.9% compared with 2019.

Using the estimated model including the cost of electricity, we conduct three counterfactual simulations to evaluate the impact of alternative policy interventions. In the first scenario, we consider the direct impact of the labeling policy: we introduce the new labeling regulation already in February 2021 by assigning predicted new labels to all products available on the market at that time. Under this counterfactual, the average energy consumption of refrigerators sold decreases modestly in all countries: Germany (–2.2%), Poland (–1.9%), Belgium (–1.8%), and France (–0.7%). These reductions are driven by a reallocation of consumer demand toward more energy-efficient models. By choosing February 2021—the last month under the old labeling regime—this exercise isolates the effect of the new labels on consumer choices and does not capture potential changes in product offerings or technological improvements that the regulation may have induced on the supply side.

Second, we simulate the impact of an alternative regulatory policy: a ban on refrigerators with the lowest energy-efficiency ratings under the new labeling system (labels F and G) in March 2021. To preserve product variety, models in these categories are replaced by 'hypothetical' products with label E, with corresponding adjustments to marginal costs and electricity consumption. This intervention leads to substantial efficiency gains: average energy usage decreases by 15.5% in France, 13.5% in Poland, 12.7% in Belgium, and 9.6% in Germany. Overall, the energy efficiency of purchased refrigerators improves markedly, although these gains come at the cost of higher equilibrium prices in the range of 6.4–9.4% due to the removal of the cheapest and lowest quality products.

Finally, we evaluate the impact of an alternative fiscal policy: a feebate scheme that subsidizes refrigerators with below-average energy consumption and taxes those with above-average consumption. Using a feebate scheme that corrects for the internality from the estimated consumer undervaluation of electricity costs, the resulting energy savings amount to 4.7% in Belgium, 4.3% in Germany, 3.4% in France, and 1.8% in Poland. Under a feebate scheme that additionally accounts for the externality associated with the social cost of CO_2 emissions from electricity consumption, the resulting energy savings amount to 6.0% in Belgium, 6.0% in Germany, 4.5% in France, and 3.2% in Poland. As in the previous two scenarios, these reductions are driven by shifts toward more energy-efficient products in consumers' purchase decisions.

These three counterfactual exercises highlight the different channels through which energy labeling policy can influence market outcomes. The direct impact of simply introducing the new labels generates modest but meaningful reductions in energy use by steering consumers toward more energy-efficient products, even without altering the underlying product portfolio. In contrast, a stricter regulatory policy banning the least efficient refrigerators delivers substantial energy efficiency gains but raises equilibrium prices by restricting the availability of low-cost options. Finally, a fiscal policy through a feebate scheme to correct for undervaluation offers an intermediate path. It yields more moderate improvements in energy efficiency than a ban, but also implies a lower impact on consumers and firms. Across all scenarios, there is substantial cross-country heterogeneity, reflecting differences in product portfolios and consumer preferences.

The remainder of the paper is organized as follows. Section 2 reviews the relevant empirical literature. Section 3.1 describes the institutional background pertinent to energy-efficiency regulations. Section 5 introduces our empirical model. Section 6 presents our empirical findings, and finally Section 8 concludes.

2 Related literature

Our paper contributes to the following streams of literature. First, several papers estimate structural demand models to understand the adoption of energy-efficient technologies. A series of studies employ structural models to evaluate the effectiveness of labeling programs, minimum efficiency standards, taxes, and subsidies (see Houde (2018, 2022), Houde and Aldy (2017), and Houde and Myers (2021)). These papers exploit various policy changes and primarily quantify their effects on refrigerator sales in the United States. They rely on a transaction-level dataset from a nationwide appliance retail chain, supplemented with information from other sources. In a related study, Cohen, Glachant, and Söderberg (2017) estimate a structural model of demand and supply using sales data on refrigerators in the United Kingdom from 2002 to 2007. They find that the main factor limiting the full impact of rising electricity prices on reducing refrigerator energy consumption is not consumer myopia, but rather shifts in relative prices that favor less efficient models. They also find that manufacturers respond strongly to increases in electricity prices by adjusting their product portfolios.[2]

Another stream of literature is focused on estimating willingness-to-pay for energy-efficient products, which, due to the scarcity of sales data, primarily utilizes stated preference methods. For instance, Sammer and Wüstenhagen (2006) conducted face-to-face interviews with Swiss consumers shopping for washing machines, using choice-based conjoint analysis to determine the value placed on eco-labels relative to other product attributes. Their findings indicated a willingness to pay a 30% premium for energy-efficient washing machines in Switzerland. Shen and Saijo (2009) employed a hypothetical choice experiment to estimate consumers' WTP for higher energy efficiency ratings on air conditioners and refrigerators in Shanghai. They find that the WTP for more energy-efficient refrigerators was higher than that for more energy-efficient air conditioners, implying that consumers have a greater incentive to pay more for appliances they use more frequently. In a related paper, Zha et al. (2020) explored consumer attitudes toward energy-efficient refrigerators and washing machines using a discrete choice experiment conducted in China in 2017. They conclude that consumers are willing to pay a premium for an improved energy-grade label on refrigerators compared to washing machines. In another study, Galarraga, González-Eguino, and

2. There is also a growing body of related literature examining the impact of food packaging regulation using structural models, for example, Allais, Etilé, and Lecocq (2015), Dubois, Griffith, and O'Connell (2020), Araya et al. (2022), Barahona, Otero, and Otero (2023), and Alé-Chilet and Moshary (2022).

Markandya (2011) employ a revealed-preference approach using data from the Spanish dishwasher market. They estimate consumers' willingness to pay (WTP) for attributes associated with energy efficiency labels and find that approximately 15.6% of the final product price reflects the value consumers place on energy efficiency. This corresponds to roughly €80 of the average market price. Panzone (2013) uses data on several million transactions in the UK over two years, 2009–2011, to estimate AIDS models for refrigerators, washing machines, TVs, and light bulbs. He concludes that consumers invest in energy efficiency when expecting electricity prices to rise in the future. Finally, Guetlein et al. (2026) use discrete choice experiments conducted on statistically representative samples in eight European countries to investigate consumers' willingness to pay for various refrigerator characteristics. They find that energy labels significantly influence the choices of consumers with high energy literacy. Moreover, they show that removing energy-inefficient refrigerators would disproportionately harm consumers with low levels of energy literacy, but not necessarily those with low incomes.

There is also a growing literature on consumer inattention and misperception regarding the true cost of purchasing and operating energy-consuming products, mainly in the car industry. For instance, Allcott (2013) provides survey evidence suggesting that car buyers may misunderstand key information on fuel economy labels and cannot often accurately compute lifetime fuel costs. Several other studies examine whether consumers fully internalize future fuel costs when purchasing vehicles. Allcott and Wozny (2014) use transaction-level data to estimate how fuel prices are capitalized into used vehicle prices and find evidence of partial, but not full, capitalization. Busse, Knittel, and Zettelmeyer (2013) analyze market-level variation in gasoline prices and vehicle sales, concluding that consumers respond to fuel costs but may exhibit some degree of inattention or myopia. Grigolon, Reynaert, and Verboven (2018) estimate a structural model of car demand in Europe and find that consumers significantly undervalue future fuel expenses, especially in segments with lower-income buyers.

In a paper closely related to ours, Houde and Myers (2026) study how heterogeneity in the perception of lifetime energy consumption influences purchase decisions. Using data on refrigerator purchases from a large appliance retailer, they document substantial heterogeneity in consumers' valuation of lifetime energy costs. Based on their estimated demand model, they compare a tax policy with an environmentally equivalent minimum efficiency standard and find that the minimum efficiency standard performs better in terms of welfare. While Houde and Myers focus on heterogeneity in perceived energy costs, our analysis emphasizes how institutional design choices—such as label rescaling, product bans, and suitable feebate schemes—shape equilibrium outcomes across countries.

Unlike existing studies that analyze incremental changes in labels or prices, we study a discrete regulatory regime change that simultaneously altered the information content, scale, and market interpretation of energy labels across multiple EU countries. To the best of our knowledge, no other papers have assessed the effectiveness of the New EU Energy Label 2021. In particular, no prior studies have utilized sales data spanning the period before and after the regulation's implementation in March 2021 to measure the average energy consumption of purchased refrigerators and analyze consumer purchasing behavior.

3 Institutional background

3.1 Energy efficiency label regulations in Europe

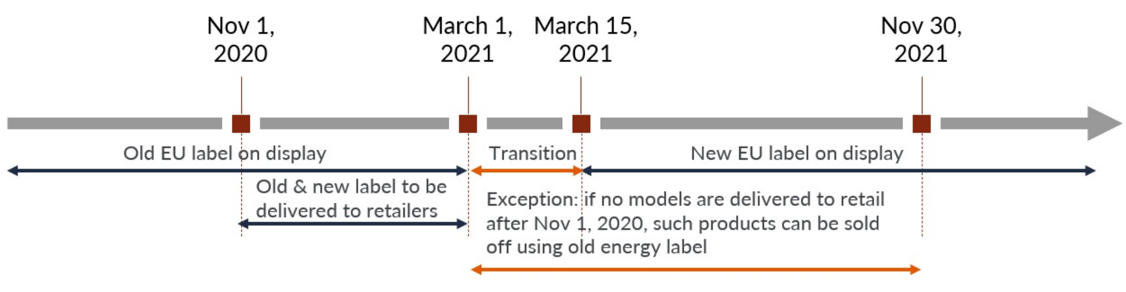
Labeling regulations The first EU-wide Energy Labeling Regulation was adopted in 1992 through the EU Directive 92/75/EC. The labeling specifications are detailed in individual implementing directives for each product type. Specifically, the first implementing directive for refrigerators and freezers was issued in January 1994 (94/2/EC) and took effect in January 1995. Each Member State was responsible for translating the directives into law and ensuring that all suppliers and dealers within their territory fulfilled their obligations. Additionally, the labeling scheme was to be supported by educational and promotional information campaigns aimed at encouraging more responsible energy use by private customers. The energy efficiency of appliances was rated in terms of energy efficiency classes from A to G, with A being the most energy-efficient and G the least. This information was also required to be included in catalogs and by internet retailers on their websites.

To keep up with advances in energy efficiency, Directive 2010/30/EU was introduced in December 2010 and required the new EU Energy Label to be displayed on all appliances from December 2011. For some product categories, the lower classes (E, F, G) were phased out due to ecodesign requirements, or they became so rare that they were no longer needed. At the same time, the "A" class was sometimes no longer enough to describe the most energy-efficient products. The directive introduced the new energy efficiency classes A+, A++, and A+++. It used pictograms instead of words, allowing manufacturers to use a single label for products sold in different countries. It also introduced the Energy Efficiency Index (EEI), an indicator of the annual power consumption relative to a reference consumption based on the storage volume and type of appliance (refrigerator or freezer). In addition, several product attributes unrelated to electricity usage were incorporated into the EEI formula. This labeling system aimed to simplify consumer understanding and comparison of different appliances' energy efficiency. The 2010 Energy label also required the reporting of electricity consumption in kWh/annum and noise level in decibels on the label.

An update to the labeling requirements for refrigerators and freezers took effect on March 1, 2021, following Regulation (EU) 2017/1369 of July 2017. This update introduced a simpler and more informative classification system, using only the letters A to G. Under the previous 2010 EU Energy Label, the continuous improvement in appliance energy efficiency meant that many products were clustered in the top categories (A+, A++, and A+++), making them appear largely undifferentiated to consumers. The new regulation was therefore designed to restore meaningful distinctions in energy efficiency among products. For example, a refrigerator previously labeled A+++ could be reclassified as B, C, D, E, or even F under the new system. The core principle of the revised framework was to keep the A category initially empty and to sparsely populate the B and C categories, thereby encouraging innovation and the development of more energy-efficient technologies.

During the transition to the rescaled A–G energy labels—effective from 1 March 2021—retailers were required to replace old labels with the new ones within 14 working days, both in physical stores and online. An exception applied to products that were placed on the EU market before 1 November 2020 and discontinued by the manufacturer, especially when re-testing under new protocols was infeasible. These discontinued models could continue to be sold with the old label only until 30 November 2021, after which they were no longer permitted to be displayed or sold. The timeline of the regulation is illustrated in Figure1.

Figure 1: Timeline of Old and New EU Labeling Regulation



Minimum ecological requirements The Eco-design Directive 2009/125/EC complements the EU Energy Labeling Regulation by setting minimum energy efficiency and environmental standards for products sold in the EU. Manufacturers must ensure compliance with these requirements, as non-conforming models are effectively banned from the market. In line with the 2021 revision of the Energy Label, the Eco-design Regulation (EU) 2019/2019 introduced stricter minimum efficiency thresholds for refrigeration appliances. These new standards, effective from March 1, 2021, led to the phase-out of the least efficient products, roughly corresponding to the former F and G classes. Together, the updated label and eco-design rules aim to promote innovation, enhance product efficiency, and enable consumers to make more sustainable choices.[3]

3. See Commission Regulation (EU) 2019/2019 laying down eco-design requirements for refrigerating appliances pursuant to Directive 2009/125/EC.

4 Data and descriptive analysis

4.1 Data

The data used in this study comes from the GfK Market Research database, which was acquired by NielsenIQ in 2023 and now operates under the NIQ brand. The dataset provides detailed product-level information on the refrigerator market in four EU countries—Belgium, France, Germany, and Poland—covering the period from January 2019 to December 2022. The dataset covers both sales volumes and prices, along with a rich set of product characteristics, and distinguishes between two distribution channels: traditional (brick-and-mortar) and online retail. The data are collected from a comprehensive sample of retailers, representing approximately 87% of total refrigerator sales in these countries. Although GfK does not release retailer-level information, the extensive product-level panel structure makes the dataset particularly well-suited for analyzing market outcomes and consumer responses to changes in labeling and energy efficiency regulations.

Each refrigerator (or "product") is described by two identifiers: (i) the brand, such as Samsung or Bosch; (ii) the model, such as RB3EJ5200SA/EF or BRB26600FWW/EF in the case of Samsung. An observation in our panel dataset is thus a product (brand and model), distribution channel (traditional or online), country, and period (month). The majority of products belong to well-known brands, including Samsung, Siemens, Miele, LG, Whirlpool, and Bosch. The initial dataset includes 713,118 observations: 122,047 for Belgium, 190,586 for France, 277,763 for Germany, and 122,722 for Poland. The monthly sales of refrigerators, measured in units per 1,000 inhabitants in the four countries, are shown in Figure B.1 in the Appendix.

We process the dataset as follows. First, we drop observations with missing or zero sales, so-called trade brands, and duplicate records. Trade brands are excluded primarily due to missing information on energy labels and energy consumption. Next, we exclude observations with missing data or outliers in prices, annual energy usage, and refrigerator dimensions. After this step, the dataset is reduced to 632,577 observations: 113,119 for Belgium, 164,148 for France, 241,429 for Germany, and 113,881 for Poland. In terms of sales coverage, we retain 84.8% of total sales for Belgium, 64.2% for France, 88.6% for Germany, and 99.9% for Poland. This indicates that trade brands account for a substantial share of total sales in France, while they are virtually absent in Poland.

We aggregate online and offline sales for identical products by country and month, which substantially reduces the number of observations relative to the raw data. The final dataset used for the reduced-form energy regressions includes 17,925 unique refrigerator models sold across the four countries, yielding a total of 412,621 product–country–month observations: 80,625 for Belgium, 107,518 for France, 158,800 for Germany, and 65,678 for Poland.

Product categories and aggregation: Following the data structure, we classify refrigerators into two main types: built-in and freestanding. Built-in refrigerators are further divided into three groups: (1) single-door models up to 90 cm; (2) single-door models over 90 cm; and (3) double-door models with a top or bottom freezer. Freestanding refrigerators follow the same three-group classification, with two additional categories: (4) models with three or more doors and (5) side-by-side refrigerators. Next, we aggregate products that share the same old and new energy labels and belong to the same brand and main product category defined above. Many products sold by the same manufacturer differ only marginally in characteristics and account for very small sales volumes, implying negligible market shares in each period. This justifies the aggregation, which groups highly similar products and reduces the number of unique items in the dataset, facilitating the estimation of plausible substitution patterns.

We discuss the energy labeling regulation in more detail in Section 3.1, while the procedure for assigning old and new energy labels is described in Appendix A.1. In brief, the old energy labels ranged from D, C, B, A, A+, A++, to A+++, whereas the new energy labels range from G, F, E, D, C, B, to A. In our analysis, we exclude products with infrequently observed labels—specifically, the least efficient old labels (A, B, C, and D) and the most efficient new labels (A and B).

After aggregation and further data cleaning—specifically, removing products and brands with very low sales—we obtain a final dataset comprising 5,932 unique products sold across four countries during the study period. Table 1 presents the distribution of unique products across these categories. The corresponding number of observations becomes: 25,953 for Belgium, 29,710 for France, 40,325 for Germany, and 17,921 for Poland.

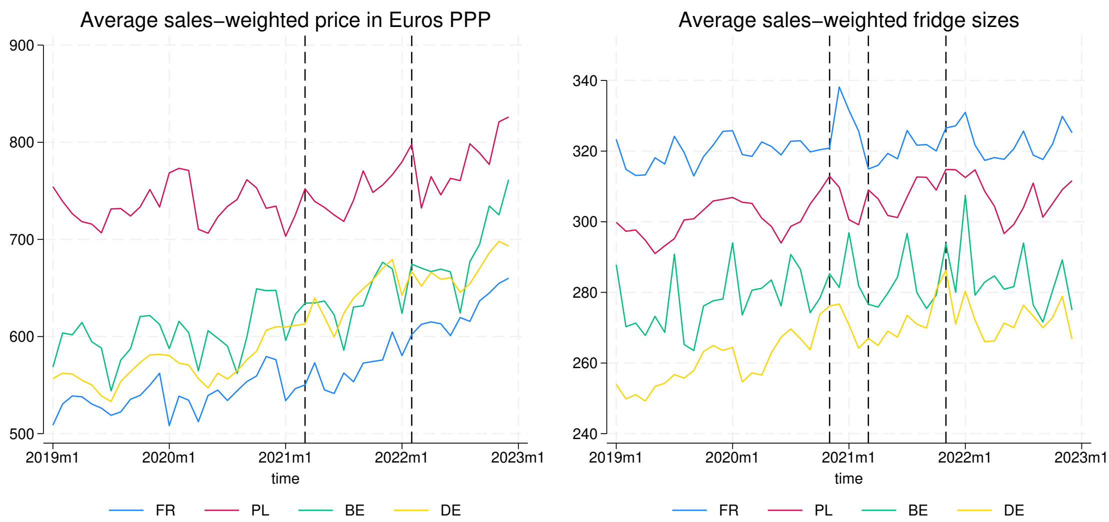
Table 1: Refrigerator types (unique products in the sample)

Main Type	**Built-in**	**Freestanding**	**Total**
1 door 81-90 cm	464	510	974
1 door > 90 cm	790	489	1,279
2 doors freezer bottom (and top)	811	1,573	2,384
2 doors freezer top	0	512	512
3+ doors	0	333	333
Side-by-side	0	450	450
Total	2,065	3,867	5,932

Figure 2 illustrates the changes in average sales-weighted prices in Euros (PPP) and refrigerator sizes over time in the countries considered.[4] Prices exhibit seasonal fluctuations and an upward trend, with the increase accelerating toward the end of the period, due to higher inflation rates. The size of sold refrigerators also shows seasonal variations and a clear upward trend, particularly in Germany, which impacts the average energy consumption.

4. Nominal prices in euros are the lowest in Poland and are rescaled by dividing them by the PPP factor, which ranges between 0.591 and 0.616 depending on period.

Figure 2: Average sales-weighted price and fridge size



4.2 Energy usage and labels

A key characteristic of refrigerators is their annual energy consumption (kWh), which is displayed on the EU Energy Label alongside the corresponding energy efficiency class. Depending on the timing of product introduction, the GfK database contains varying information: some models report both old and new energy consumption values, while others include only one of these measures. The same applies to the associated efficiency labels.

To ensure consistency, before the product aggregation discussed above, we construct harmonized measures of energy consumption. When the new energy consumption value is available for a product, we use it; otherwise, we rely on the old measure. For observations where both values are missing (1,698 cases before aggregation), energy consumption is imputed using information from the European Product Registry for Energy Labelling (EPREL), an EU-wide database providing detailed product-level information on the energy performance of appliances sold in the European Union.[5] Because the methodologies for measuring energy consumption differ between the old and new labeling schemes, these differences may influence the observed average energy efficiency of refrigerators sold during the transition period.

Figure 3 presents sales-weighted annual energy consumption between January 2019 and December 2022 relative to Germany in January 2019. In all four countries in our data, there was a decline in the average energy consumption of purchased products after March 2021. In particular,

5. Manufacturers and importers are legally required to register their products in EPREL before sale, making it a comprehensive reference source for regulated product categories, including refrigerators, washing machines, air conditioners, televisions, and lighting equipment. However, EPREL cannot serve as the primary data source for energy usage in our study because product identifiers differ substantially between the GfK and EPREL databases, and many products sold in earlier years of our sample are not covered in EPREL.

comparing the average energy consumption in March 2021 with that in the last period of the data, December 2022, there was a decline of 3.1% in France, 4.8% in Poland, 5.4% in Germany, and 7.3% in Belgium.

However, the sales-weighted annual energy consumption does not capture changes in the product range and characteristics over time. To address this, we use a regression framework that accounts for the impact of refrigerator attributes on annual energy consumption (kWh per year), while also controlling for differences in the portfolio of products sold. Specifically, we estimate the following hedonic model specification:

$$\log(e_{jct}) = w_{jct}\beta_c + \delta_{ct} + u_{jct}, \tag{1}$$

where $\log(e_{jct})$ denotes the logarithm of the annual energy consumption of refrigerator j available in country c in month t.[6] The vector w_{ict} accounts for the refrigerator characteristics, and the error term is denoted by u_{jct}.

The coefficients δ_t are monthly fixed effects that represent monthly energy consumption levels after adjusting for the refrigerators' characteristics. We convert them into a quality-adjusted energy consumption index, using the transformation $\exp(\delta_t)$, which may be interpreted as reflecting technological progress. We estimate the vector of coefficients $\gamma = (\alpha, \beta, \delta)$ in two ways: simple ordinary least squares (OLS) and weighted least squares, using sales in a given month as weights.

Among refrigerator characteristics, we include dummy variables to indicate the main types of refrigerators, distinguishing between single-door models up to 80 cm, those between 81–90 cm, and those above 90 cm in height. We also differentiate between double-door refrigerators with the freezer located either at the top or bottom, as well as three-door and side-by-side models. These categorical variables are interacted with the logarithms of refrigerator dimensions—namely depth, width, height, and total capacity in litres—to allow for a flexible functional form that captures the effect of size on energy consumption.

Furthermore, the characteristics include information on whether the refrigerator is freestanding or built-in, as well as the type of front decoration, distinguishing between materials such as stainless steel and other decorative panels. The cooling system is another crucial determinant, capturing the presence of no-frost technology, which can be either partial or full, along with the type of cooling mechanism, including ventilated air circulation, inverter motors, and the presence of an additional cooling compressor. Features related to temperature regulation, such as separate temperature control and the inclusion of a chiller zone, are also accounted for.

We control for convenience-related attributes, particularly water and ice dispensing features. These include the presence of a water dispenser, a water container, a direct water connection, an

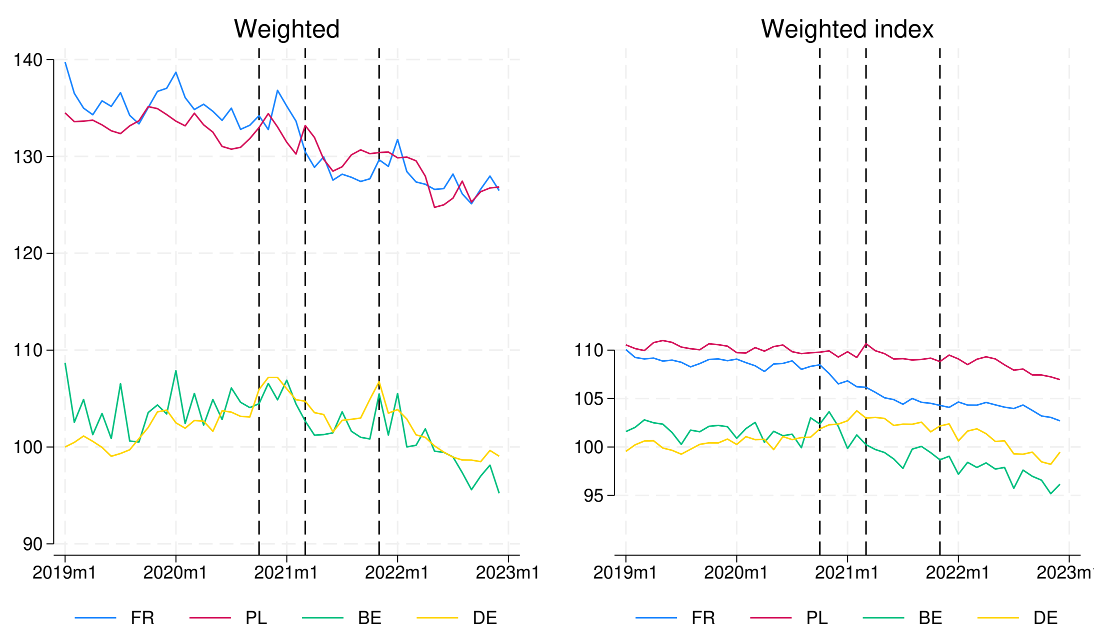
6. As a robustness check, we also estimate the model without taking logarithms, which yields a similar quality-adjusted energy consumption index.

ice cube dispenser, and a crushed ice function. Additional features such as the number of drawers, the presence of a digital display, smart connectivity, LED lighting, and the mounting mechanism (either door-mounted or sliding) are included in the specification.

The estimation results for equation (1) are reported in Table B.1 in the Appendix. The refrigerator's physical dimensions—width, depth, height, and total capacity in litres—interacted with the main refrigerator-type dummy variables emerge as the most significant determinants of energy usage. In addition, several other product features included as dummy variables exert a notable influence on energy consumption. These include whether the appliance is built-in or freestanding, the location of the freezer compartment, and additional features such as ice cube dispensers, chiller zones, ventilated air circulation, digital displays, smart connectivity, and no-frost technology.

The quality-adjusted annual energy consumption index is presented in Figure 3, illustrating changes in the average energy consumption of refrigerators sold each month across the four countries in our analysis between January 2019 and December 2022, after controlling for product portfolios and their attributes. Between March 2021 and December 2022, after adjusting for refrigerator characteristics that impact energy consumption, the decline was 3.3% in France, 3.5% in Poland, 3.4% in Germany, and 4.2% in Belgium.

Figure 3: Left panel: sales-weighted average annual energy consumption (kWh). Right panel: quality-adjusted index (2019m1 in Germany = 100).



Based on these results, there was a significant but modest decline in the average energy efficiency of products sold in these four countries between March 2021 and December 2022. While controlling for refrigerator characteristics reduces cross-country differences and changes over time, it does not significantly alter the overall trend over time. This finding highlights the need for further investigation using a structural model of demand and supply, which we discuss in the next section.

Old and New Energy Labels For some products with old energy labels, sales were still recorded after March 2021, and no information on the new energy labels was available in the data. This may be because these products continued to be sold with old labels even after the regulation was introduced in March 2021, as discussed in Section 3.1. For such products without new labels, we predicted the missing labels using product characteristics and a random forest algorithm. The algorithm achieved a 99% in-sample prediction accuracy for cases where both old and new labels were known. Consequently, all products sold after March 2021 are assigned a new label in the data. Figure 4 illustrates the transition from old to new energy labels after infrequent labels were excluded.

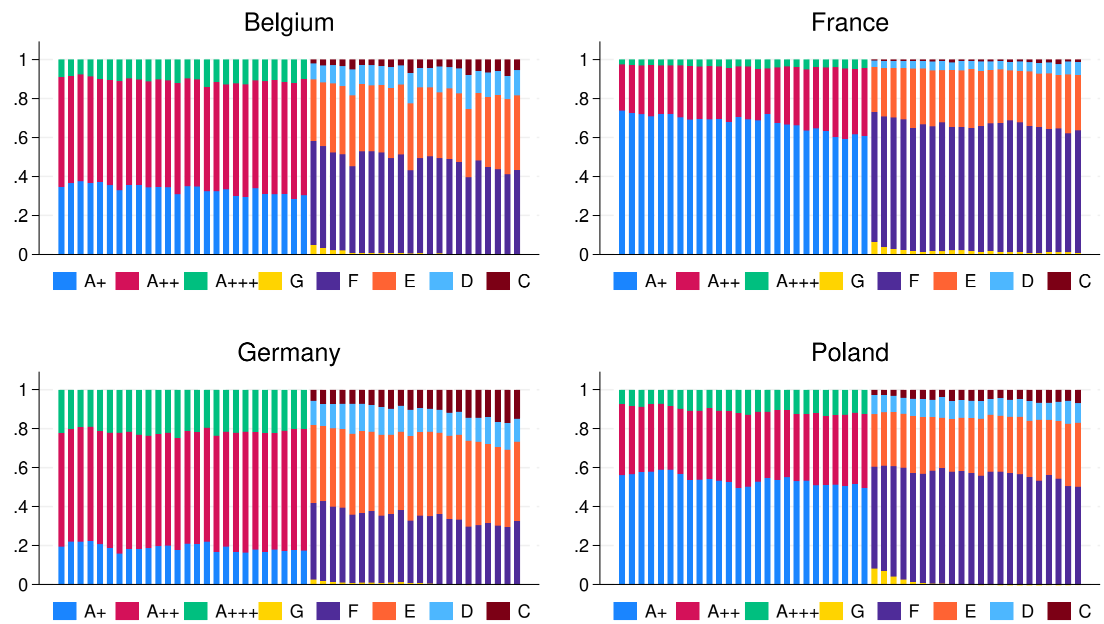
There are notable differences across countries in the sales of products with different labels. Germany had the highest sales of products with the old A+++ and A++ labels, which are replaced by products with the new labels E, D, and C. Sales of the A+++ and A++ refrigerators in Belgium are lower than in Germany, but higher than in France and Poland. The shift to the new labels E, D, and C is proceeding at a slower pace in Belgium compared to Germany, yet more rapidly than in Poland and France. Poland is positioned third in terms of the proportion of products with the old A+++ and A++ labels and is similarly ranked in the transition to the new labels E, D, and C. France appears to be lagging in the transition, which may, however, be because we lost a larger share of sales than in other countries by dropping trade brands, as discussed above.

4.3 Refrigerator and electricity prices

According to a recent survey conducted by EPREL (see Figure B.2 in the Appendix), consumers primarily base their refrigerator purchase decisions on two factors: the upfront purchase price and expected electricity costs over the appliance's lifetime. Table 2 reports average sales-weighted refrigerator prices, expressed in euros (PPP), over the period 2019–2022 by energy-efficiency label, together with the corresponding total cost of ownership that includes electricity expenditures over a 15-year horizon, computed using prevailing kWh prices. Note that electricity prices increased substantially over this period, particularly in Belgium, as shown in Figure A.1.

Table 2 reveals several important patterns. First, more energy-efficient refrigerators generally have higher purchase prices, potentially reflecting a higher quality and production costs. However, once electricity costs are taken into account, these price differences are substantially attenuated and in some cases even reversed. Second, there is considerable cross-country heterogeneity in both purchase prices and total lifetime costs. For example, France and Belgium show smaller differences in total costs across energy labels than Germany and Poland. Overall, these patterns suggest that there is a trade-off between refrigerator price and the lifetime electricity costs. The question is

Figure 4: Old and new energy labels between January 2019 and December 2022



whether information on energy consumption and energy labels steer demand toward more energy-efficient appliances. Addressing this question requires estimating a demand model that incorporates both the refrigerator and electricity prices.

Table 2: Average refrigerator prices and total cost including electricity over 15 years (Euros)

	Refrigerators				**Refrigerators + electricity (15 years)**			
Label	Belgium	France	Germany	Poland	Belgium	France	Germany	Poland
C	701	795	713	1,018	1,515	1,367	1,577	1,777
D	818	873	841	932	1,647	1,524	1,723	1,860
E	675	617	628	827	1,524	1,392	1,710	1,888
F	600	560	594	676	1,589	1,455	1,740	1,873
G	525	594	562	832	1,522	1,580	1,889	2,240
A+++	783	836	733	938	1,424	1,353	1,534	1,754
A++	637	612	558	856	1,464	1,323	1,591	1,925
A+	471	491	420	614	1,473	1,375	1,585	1,730

5 Structural Model

We first present the demand model, specifying how consumers choose among a wide range of differentiated refrigerators (Subsection 5.1). Next, we discuss the oligopolistic supply side, where marginal costs depend on several relevant product characteristics (Subsection 5.2). Both parts are essential to perform our subsequent policy counterfactuals.

5.1 Demand

Overview In principle, consumer utility should depend on both the energy label and the underlying electricity costs. However, separating these two effects is empirically difficult. Moreover, when making purchase decisions, consumers may not be fully aware of the electricity costs associated with a particular refrigerator, which are shown in Table 2. We therefore consider two alternative utility specifications, each with distinct advantages and limitations.

First, in the *labels* specification, utility depends directly on the energy label—namely, the old labels used before March 1, 2021, and the new labels introduced thereafter—but not on electricity costs. The interpretation is that consumers use the label as a heuristic or proxy for expected operating costs. Second, in the *electricity cost* specification, utility depends on the expected electricity costs implied by the label rather than on the label itself. These costs are computed using the portfolio of products available in each country and period. This specification allows us to quantify more directly the extent to which consumers correctly value—or undervalue—electricity costs relative to price.

Consumer choices are also influenced by other product characteristics and by constraints related to kitchen design and available space. These factors imply limited or no substitution across the main refrigerator types. As discussed earlier, we classify refrigerators into two broad categories: built-in and freestanding, between which substitution is not allowed. Based on product dimensions, we further define three nests for built-in refrigerators and six nests for freestanding refrigerators. This nesting structure captures the possibility of stronger substitution within than between nests.

Utility More formally, the nested logit choice model can be described as follows. A *market* is defined by country c, product category m (freestanding or built-in), and period t. In each market and period, there are M_{cmt} potential consumers. For brevity, we omit the period and category subscripts in what follows. Each consumer i in country c chooses among J_c differentiated refrigerator models ($j = 1, \dots, J_c$) or the outside good ($j = 0$). The choice set is divided into *nests* g, as defined above. The indirect utility of consumer i in country c from choosing product j is specified as:

$$u_{ijc} = \underbrace{x_{jc}\beta_c - \alpha_c p_{jc} - \alpha_c \gamma_c G_{lc} + \lambda_{lc} + \xi_{jc}}_{\delta_{jc}} + \zeta_{igc} + (1-\sigma)\varepsilon_{ijc}, \tag{2}$$

where δ_{jc} is the mean utility for product j in country c, ζ_{igc} represents a group-specific valuation common to all products within the same nest g, and ε_{ijc} is an individual-specific valuation for product j, assumed to be an i.i.d. extreme value. The nesting parameter $\sigma \in (0, 1)$ captures the degree of preference correlation among products within the same group and takes values between

0 and 1. A higher σ indicates stronger substitution between products in the same nest. If $\sigma = 0$, a multinomial logit model is obtained without preference correlation for products in the same nests.

The mean utility of the outside good 0 is normalized to zero, i.e., $\delta_{0c} = 0$. The mean utility of the refrigerator models $j = 1, \cdots, J_c$, δ_{jc}, depends on a vector of product characteristics x_{jc} of model j sold in country c, such as size, various features and brand effects, and on the price p_{jc} of the product j in country c. It also depends on either the expected electricity costs associated with label l in country c of product j, G_{lc}, or on a fixed effect for label λ_{lc}. Finally, ξ_{jc} is an unobserved quality term specific to the country c and product j.

In our *labels* specification, we restrict γ_c to be zero, thus omitting the term G_{lc} and estimating the fixed effects λ_{lc} for each label in each country. Note that this separately includes old labels (for the period before March 1, 2021) and new labels (for the subsequent period). With this flexible specification, we can estimate, in each country, the willingness to pay for both old and new labels relative to the lowest label in each system, by dividing the fixed effects by the price coefficient α_c, i.e., λ_{lc}/α_c. On this basis, we assess whether consumers over- or underestimate the value of labels compared to the actual savings in electricity costs over a 15 year horizon. However, since these estimates are relative, the interpretation also depends on consumer valuation of the base categories.

Conversely, in the *electricity cost* specification, we restrict λ_{lc} to be zero, thus omitting the label fixed effects and estimate a valuation coefficient γ_c for the present value of the expected electricity cost G_{lc} over a refrigerator's lifetime, where $\gamma_c < 1$ refers to undervaluation and $\gamma_c > 1$ refers to overvaluation. To measure G_{lc}, we begin with model j's annual electricity consumption (in kWh), denoted e_{jc}, and impose several behavioral assumptions.

First, consumers are typically not aware of a model's exact electricity consumption e_{jc}. Instead, they interpret energy labels as signals of relative energy use across products. We therefore assume that consumers are aware of the average electricity consumption associated with a given label l, denoted e_{lc}. This assumption is consistent with evidence from Davis and Metcalf (2016), who show that U.S. consumers respond primarily to simplified or salient cost information rather than to detailed technical attributes.

Second, we assume that consumers operate the refrigerator continuously throughout the year and expect to use it for $S = 15$ years. Third, we assume that consumers expect the electricity price per kWh to remain constant over time. Formally, the expected price at time s in country c is equal to the current price, $\mathbb{E}(g_{sc}) = g_c$. This assumption is commonly used in the literature; see, for example, Houde and Myers (2026) for a recent application. Finally, the annual interest rate is r. The present value of expected future electricity costs associated with label l in country c can be written as:

$$G_{lc} = \rho \, g_c \, e_{lc},$$

where $\rho = (1/r) \cdot \left(1 - (1+r)^{-S}\right)$ is a capitalization coefficient (e.g., $\rho = S$ as $r \to 0$).[7]

The *labels* specification is more flexible because it includes a fixed effect for each old and new label (relative to a base) and for each country, amounting to a total of 6 effects over 4 countries. The *electricity cost* specification puts more structure, by estimating 2 undervaluation coefficients (one before and one after the regulation) for each country. Although this is somewhat more restrictive, it also creates a basis for conducting some of the policy counterfactuals. As such, the two approaches provide complementary insights.

Estimation Assuming consumers choose the product that provides the highest utility results in an aggregate market share system for each product. The market share system can be inverted to obtain the following estimating equations (Berry (1994)).

Labels specification:

$$\ln s_{jc}/s_{0c} = x_{jc}\beta_c - \alpha_c p_{jc} + \lambda_{lc} + \sigma \ln s_{j|gc} + \xi_{jc},$$

Electricity cost specification:

$$\ln s_{jc}/s_{0c} = x_{jc}\beta_c - \alpha_c p_{jc} - \alpha_c \gamma_c G_{lc} + \sigma \ln s_{j|gc} + \xi_{jc},$$

where $s_{jc} = q_{jc}/M_c$ is the market share of product j (sales volume divided by the potential market size M_c in country c), s_{0c} is the market share of the outside good, and $s_{j|gc}$ is the market share of product j within group g.

The demand model enables the computation of consumer surplus and price elasticities. The elasticity of demand for product j with respect to the price of product k is given by:

$$\frac{\partial s_j}{\partial p_k}\frac{p_k}{s_j} = -\alpha_c \left(\frac{1}{1-\sigma} D_{jk} - \frac{\sigma}{1-\sigma} s_{j|g} D^g_{jk} - s_j\right) p_j, \tag{3}$$

where $D_{jk} = 1$ if $j = k$ (own-price elasticity) and $D^g_{jk} = 1$ if j and k belong to the same group (cross-price elasticity within the same group). Products in the same group have higher cross-price elasticities than those in different groups. The formula allows us to calculate substitution patterns within (e.g., freestanding side-by-side refrigerators) and across product nests and assess how prices and product characteristics affect demand.

The demand equation is estimated using instrumental variables (IV) to account for the endogeneity of the price variable p_{jc} and the within-group market shares $s_{j|gc}$, both of which may be positively correlated with the error term. A positive unobserved demand shock for a given product

7. This specification follows a similar one used in the automobile demand literature, such as Allcott and Wozny (2014) and Grigolon, Reynaert, and Verboven (2018). A key simplifying feature in our setting is that annual usage is constant across consumers (as a refrigerator is constantly used), whereas in automobile demand, consumers differ in their annual mileage.

increases its within-group market share and simultaneously raises its price. As instruments, we use the variables suggested by Berry, Levinsohn, and Pakes (1995): sums of characteristics and counts of the number of products across all of the firm's other products and across all competing firms' products in the same market (defined by period and country). These instruments are constructed for a wide range of observable characteristics, such as product dimensions, noise level, and technical and design features.

5.2 Supply

We assume multi-product Bertrand price-setting firms to infer marginal costs and current economic profits, and to perform policy counterfactuals. For simplicity, we now also remove the country subscript c. Let F_f be the set of products sold by firm f. The profits of firm f are given by:

$$\Pi_f(p) = \sum_{k \in F_f} (p_k - c_k) s_k(p) M \tag{4}$$

where c_k is the constant marginal cost of product k in country c, and $s_k(p)$ is product k's market share in country c as a function of the price vector in country c. The first-order conditions that define the Bertrand-Nash equilibrium are given by:

$$s_j(p) + \sum_{k \in F_f} (p_k - c_k) \frac{\partial s_k(p)}{\partial p_j} = 0 \tag{5}$$

for products $j = 1, \ldots, J$. This can be written in vector notation as:

$$s(p) + (\theta^F \odot \Delta(p))(p - c) = 0 \tag{6}$$

where p and $s(p)$ are $J \times 1$ price and market share vectors, $\Delta(p) \equiv \frac{\partial q(p)}{\partial p'}$ is a $J \times J$ matrix of own- and cross-price derivatives, θ^F is a $J \times J$ block-diagonal matrix, with ones for products of the same firm and zeros otherwise, and $\odot$ denotes element-by-element multiplication of two matrices.

The system of first-order conditions (6) can be inverted at the current price and market shares to back out the current marginal cost vector c^0:

$$c^0 = p + (\theta^F \odot \Delta)^{-1} s \tag{7}$$

For our policy counterfactuals, it is useful to know how the backed-out marginal costs depend on product characteristics. We specify the marginal cost of product j as:

$$\ln c_j^0 = w_j \delta + \mu_l + \omega_{jc},$$

where w_j is a vector of characteristics that may affect marginal costs and μ_l are the energy label-specific marginal costs.

Counterfactuals After recovering marginal costs and estimating the marginal cost parameters, the system of first-order conditions can be used to simulate counterfactual policy scenarios. A policy intervention generates demand and/or cost shocks that lead to a new price equilibrium and affect sales, profits (as defined in (4)), and consumer surplus. Formally, this involves solving the system of equations in (6) to compute the new equilibrium price vector p^1 following a policy-induced demand or cost shock. Given these prices, the corresponding equilibrium sales s^1M and other market outcomes can then be computed.

More specifically, we consider three policy counterfactuals. The first counterfactual evaluates the impact of the new labeling regulation by computing the market outcome that would have prevailed had the new labels been applied to the pre-reform portfolio of refrigerators (in February 2021, the month preceding the actual introduction of the new labels). The second counterfactual evaluates the impact of banning the lowest efficiency labels, F and G. A simple approach would be to remove all products carrying these labels (as of March 2021). However, doing so would also reduce product variety and therefore would not isolate the pure effect of the policy. To keep product variety constant, we instead simulate a policy that requires all refrigerators previously labeled F or G to meet the requirements of label E. This policy changes both the mean consumer valuation and the marginal production costs of the affected products, thereby altering equilibrium prices.

The third counterfactual evaluates the impact of a feebate policy based on the average electricity cost associated with each label. A feebate combines a subsidy ("rebate") for energy-efficient products with a tax ("fee") on energy-intensive ones and has been implemented in the automobile sector in several countries (see, for example, Adamou, Clerides, and Zachariadis (2014) and Durrmeyer and Samano (2018)). We focus on a feebate rather than a simple subsidy for two reasons. First, a subsidy requires government expenditures, whereas a feebate can be designed to be revenue-neutral. Second, a subsidy shifts demand toward more efficient products but also increases overall demand, which may lead to higher aggregate energy consumption. By contrast, a feebate primarily affects the composition of demand across products without necessarily expanding total market size.

Formally, we consider the following feebate scheme:

$$t_{lc} = \tau_c \left(G_{lc} - \tilde{G}_c \right), \tag{8}$$

where τ_c denotes the feebate rate per unit of electricity cost and $\tilde{G}_c$ is the pivot point. Products with electricity costs above $\tilde{G}_c$ are taxed, while those with costs below $\tilde{G}_c$ receive a subsidy. In practice, the policy therefore subsidizes energy-efficient labels and taxes energy-intensive ones at the same rate.[8]

Implementing the feebate scheme amounts to setting the feebate rate τ_c and the pivot point $\tilde{G}_c$. The feebate rate can be a Pigouvian tax that accounts for two market failures that are responsible for excessive demand for energy-intensive products: an internality associated with the undervaluation of private electricity costs, and an externality associated with the social costs from energy emissions. The Pigouvian feebate rate would then be equal to $\tau_c = 1 - \gamma_c + \psi$, where $1 - \gamma_c$ is the internality reflecting the part of the electricity cost that consumers fail to take into account ("belief error"), and ψ is the standard emission externality measured per euro of lifetime electricity expenditure (15 years). [9]

We set the pivot point $\tilde{G}_c$ equal to the simple average 15-year electricity cost of refrigerators sold in each country during the period considered in the counterfactual. With this choice of pivot, the feebate is approximately revenue-neutral and leaves aggregate refrigerator sales largely unchanged, up to second-order demand responses. While the pivot point determines the distribution of subsidies and taxes across products, it does not affect the marginal corrective incentive, which reflects the internality and externality components.

For each of the three policy scenarios, we compute the implied refrigerator sales by type and the resulting changes in average energy consumption in each country.

6 Empirical Results

We begin by presenting the estimates from the two nested logit demand specifications. We then discuss what the estimated coefficients for energy labels and electricity costs imply about consumers' valuation of energy savings. Finally, we report the results from the marginal cost and energy usage regressions.

As discussed above, we consider two alternative demand specifications. The first, referred to as the *labels* specification, includes fixed effects for the old and new energy labels, defined relative to a base category within each labeling system. This specification excludes electricity costs, which are inherently correlated with the labels. Under this formulation, consumers are assumed to interpret the labels as qualitative indicators of energy efficiency rather than translating them directly into quantitative cost implications.

The second specification, the *electricity cost* specification, excludes the label fixed effects and instead incorporates the average electricity cost associated with each label. In this case, consumers are assumed to respond directly to expected electricity costs, proxied by the average electricity expenditures corresponding to the respective label categories.

8. This formulation applies the policy at the label level using average electricity costs G_{lc}. A more precise approach would implement the feebate at the product level using product-specific electricity costs G_j.

9. For the internality, we use the undervaluation estimates γ_c from our demand model. For the externality, we rely on external information as outlined in Appendix A.3.

6.1 Demand estimates

Table 3 reports the parameter estimates, focusing on those that are allowed to vary across countries. The signs and magnitudes of the coefficients are intuitive and broadly consistent with expectations. The price coefficient, α, is negative and statistically significant in all countries, and slightly larger in absolute value in France than in the other countries. Consumers in all markets prefer larger refrigerators (measured in litres), although the strength of this preference differs across countries, consistent with the descriptive patterns shown in Figure 2. French consumers exhibit the strongest preference for larger refrigerators, followed by Belgian consumers, while size preferences are noticeably weaker in Poland and Germany. These cross-country differences may reflect cultural and economic factors, such as average household size, available living space, and shopping frequency.

Country-specific brand effects are also included in the model but omitted from the table for brevity. These effects are statistically significant and heterogeneous across countries, highlighting the importance of domestic brand reputations. Monthly time dummies capture seasonal fluctuations in demand, while country-specific trends indicate that market dynamics evolve differently across countries. We also include a Covid dummy for the lockdown period, April 2020, where there was a visible drop in sales (see Table B.1 in the Appendix).

Table B.2 in the Appendix shows the estimation results for the parameters that are common across the four countries. In both the *labels* and the *electricity cost* specifications, the nesting parameter σ is large and significant (respectively 0.842 and 0.683), suggesting a substantial degree of substitution between products within the same nest. The valuations for several other features are also of the expected sign and significant in both specifications. For example, freestanding models are valued less than built-in ones. Noisier refrigerators (measured in decibels) are consistently less preferred. The estimates also reveal comparable heterogeneous preferences for exterior finishes (captured by the "deco" dummies) and positive valuations for features such as separate temperature controls, full no-frost, LED lighting, ice cube dispensers, and smart connectivity.

6.2 Energy Label and Electricity Cost Valuations

We now turn to the estimated valuations of the energy labels (first specification) and electricity costs (second specification).

Label Specification The results indicate that the introduction of the new labeling scheme reduced average consumer utility in all countries except Poland, as reflected by the negative and statistically significant coefficients on the *New label dummy* in Table 3. This decline likely captures transitional effects associated with the policy change rather than a genuine reduction in consumer welfare. Consequently, it is more informative to focus on the relative valuations of the individual energy labels.

Table 3: Demand Estimation Results: Electricity Cost and Label Specifications

Panel A: Labels				
	Belgium	France	Germany	Poland
Price (α_c)	-0.0028***	-0.0036***	-0.0025***	-0.0027***
	(0.000)	(0.000)	(0.000)	(0.000)
log(total litres)	1.1751***	1.5894***	0.2871***	0.2691***
	(0.058)	(0.059)	(0.085)	(0.082)
log(freezer litres)	0.0515***	0.2707***	0.2321***	0.6921***
	(0.009)	(0.012)	(0.011)	(0.020)
No freezer	-0.2961***	-0.0111	0.0136	0.8992***
	(0.032)	(0.041)	(0.042)	(0.064)
Covid	-0.9652***	-1.2975***	-0.1636***	-0.4168***
	(0.051)	(0.049)	(0.038)	(0.058)
Time	0.0024**	0.0027***	0.0013*	-0.0048***
	(0.001)	(0.001)	(0.001)	(0.001)
New label dummy	-0.4313***	-0.2417***	-0.2801***	-0.0370
	(0.062)	(0.056)	(0.053)	(0.084)
New C	1.1396***	1.3226***	1.3128***	1.1058***
	(0.075)	(0.089)	(0.065)	(0.090)
New D	0.9417***	0.8332***	0.9680***	1.3330***
	(0.065)	(0.056)	(0.057)	(0.085)
New E	0.6406***	0.4730***	0.4656***	0.4846***
	(0.061)	(0.046)	(0.054)	(0.075)
New F	0.3692***	0.2597***	0.3567***	0.2071***
	(0.059)	(0.048)	(0.052)	(0.078)
Old A+++	0.6291***	0.8368***	0.7426***	1.1875***
	(0.038)	(0.059)	(0.037)	(0.061)
Old A++	0.3061***	0.1833***	0.2771***	0.4436***
	(0.021)	(0.024)	(0.017)	(0.025)
Brand dummies	yes	yes	yes	yes
Month dummies	yes	yes	yes	yes
Panel B: Electricity cost				
	Belgium	France	Germany	Poland
Price (α_c)	-0.0020***	-0.0028***	-0.0021***	-0.0020***
	(0.000)	(0.000)	(0.000)	(0.000)
log(total litres)	0.9809***	1.2940***	0.2689***	-0.0682
	(0.047)	(0.052)	(0.076)	(0.077)
log(freezer litres)	-0.0086	0.1878***	0.1826***	0.5578***
	(0.008)	(0.011)	(0.009)	(0.017)
No freezer	-0.4806***	-0.2570***	-0.2608***	0.5866***
	(0.030)	(0.037)	(0.036)	(0.058)
Covid	-0.8680***	-0.1771***	-0.3436***	-1.2162***
	(0.049)	(0.037)	(0.055)	(0.047)
Time	0.0063***	0.0057***	0.0038***	-0.0025**
	(0.001)	(0.001)	(0.001)	(0.001)
Old (γ_c)	0.3406***	0.3754***	0.5512***	0.8242***
	(0.024)	(0.041)	(0.033)	(0.060)
New (γ_c)	0.4690***	0.4204***	0.5994***	0.7921***
	(0.027)	(0.040)	(0.037)	(0.056)
Brand dummies	yes	yes	yes	yes
Month dummies	yes	yes	yes	yes

Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 4 presents the estimated willingness to pay for each energy label, calculated as λ_{lc}/α_c, relative to label A+ under the old system and label G under the new system. Across countries, consumers consistently exhibit higher WTP for more energy-efficient labels, confirming that labeling effectively signals product quality and energy performance. An exception is the reversed valuation of labels C and D in Poland.

There are notable differences across countries. Under the old labeling system, Polish and German consumers exhibit higher WTP than their Belgian and French counterparts. Under the new system, German consumers display the highest WTP for label C (525 euros), while Polish consumers place a relatively strong value on label D (494 euros), and Belgian consumers on label E (229 euros), each relative to the base category G. These numbers represent a substantial share of the average price of refrigerators in top new categories C and D and old category A+++, which are reported in Table 2.[10]

To assess whether consumers correctly account for operating costs when making purchase decisions, the estimated willingness to pay may be compared to future energy savings. However, our estimates are identified only relative to the base energy labels under the old and new regulations, for which utility levels are normalized and therefore not directly estimated. As a result, WTP cannot be compared to energy savings in absolute terms.

Instead, to assess whether consumers value energy efficiency in a way that is consistent with future savings, one may compare the estimated relative differences in willingness to pay across energy labels with the relative differences in expected electricity costs. For example, in Belgium, the estimated WTP difference between labels A++ and A+++ is 116 euros (i.e., 225 − 109 euros), while the corresponding difference in average 15-year electricity costs is 186 euros (i.e., 361 − 175 euros). In France, these figures are 181 euros and 194 euros, respectively; in Germany, 186 euros and 232 euros; and in Poland, 276 euros and 253 euros.

A similar pattern emerges when comparing labels E and F. The estimated willingness-to-pay (WTP) differences amount to 97 euros in Belgium (i.e., 229 − 132 euros), 59 euros in France, 43 euros in Germany, and 102 euros in Poland. The corresponding differences in lifetime electricity costs are 140 euros (i.e., 147 − 7 euros), 120 euros, 63 euros, and 135 euros, respectively. Overall, these comparisons suggest that consumers partially—but not fully—internalize future electricity costs when choosing refrigerators. In other words, expected energy savings are systematically undervalued relative to their full monetary magnitude.

Electricity Cost Specification The second specification explicitly links consumer utility to the average electricity cost associated with each label. This allows us to test whether consumers internalize energy costs when making purchase decisions rather than relying solely on the qualitative

10. For comparison, Houde (2022) estimates WTP for the *Energy Star* label in the U.S. between 16*and* 75, corresponding to roughly 1.2–5.7% of the average refrigerator price.

Table 4: Willingness to Pay and Electricity Cost Savings by Energy Class

	Willingness to Pay				**Electricity (15 years)**			
	Belgium	France	Germany	Poland	Belgium	France	Germany	Poland
C	407	367	525	410	182	414	463	650
D	336	231	387	494	168	335	445	480
E	229	131	186	179	147	211	244	347
F	132	72	143	77	7	91	181	212
G	base	base	base	base	base	base	base	base
A+++	225	232	297	440	361	368	362	300
A++	109	51	111	164	175	173	131	47
A+	base	base	base	base	base	base	base	base

Notes: The omitted reference energy class is G for new labels and A+ for old labels.

efficiency signal conveyed by the label.

The results, reported in the bottom panel of Table 3, indicate that consumers in all countries systematically undervalue electricity costs in their purchase decisions, as reflected by estimates of $\gamma_c < 1$ under both labeling regimes. The degree of undervaluation is highest among Belgian and French consumers, followed by German consumers, and in all three cases, the gap narrows modestly after the 2021 reform. Polish consumers exhibit the smallest degree of undervaluation, although it increases slightly under the new labeling scheme.

These findings are consistent with recent survey evidence conducted in November–December 2023 in six EU countries, showing that French households are the least concerned with energy savings at home. For instance, 78% of Polish respondents reported purchasing energy-efficient appliances to reduce energy use, compared with 59% in Germany and only 48% in France (Belgium was not surveyed). Moreover, when asked, "In which areas do you primarily take actions to save energy?" 32% of Polish respondents answered "home appliances," compared with 36% in Germany and only 19% in France.[11]

The persistent undervaluation of energy costs suggests that labels and energy-use information alone may be insufficient to stimulate the adoption of energy-efficient appliances. Such measures should therefore be complemented by targeted information campaigns, behavioral nudges, or fiscal incentives designed to make energy savings more apparent to consumers.

6.3 Marginal cost estimates

Table 5 presents the results of the regressions of marginal costs—which we have inferred using equation 7 from the two nested logit model specifications—on product characteristics. Column (1) is based on the *electricity cost* specification, and column (2) on the *labels* specification. The estimated marginal cost parameters are broadly consistent across specifications. In particular,

11. "Social attitudes towards energy, energy transition and environmental policy in the EU," published 7 October 2024, DOI:10.17632/xpx2z7y29p.1.

marginal costs tend to be higher for more energy-efficient refrigerators, as indicated by the positive coefficients on the corresponding energy labels.

The estimated coefficients from these regressions are used in the counterfactual simulations based on the label and electricity cost demand models. Specifically, the marginal cost estimates are employed to adjust refrigerators' marginal costs.

Table 5: Marginal costs regression (OLS): Electricity cost vs. labels specifications

	(1) Elect. costs	**(2) Labels**
New C	0.609***	0.389***
	(0.024)	(0.010)
New D	0.643***	0.400***
	(0.019)	(0.007)
New E	0.431***	0.275***
	(0.016)	(0.007)
New F	0.306***	0.214***
	(0.016)	(0.006)
Old A+++	0.498***	0.291***
	(0.011)	(0.004)
Old A++	0.195***	0.120***
	(0.007)	(0.003)
Product characteristics	yes	yes
Observations	91,204	91,204
R-squared	0.730	0.864

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, $*p$¡0.1.

7 Counterfactual Scenarios

In this section, we utilize the structural framework to conduct counterfactual policy simulations. We focus on the *electricity cost* specification of nested logit demand, combined with an oligopolistic supply model of Bertrand–Nash price competition.

Table 6 presents the predicted impact on average energy consumption under three policy scenarios. In panel (1), we consider the impact of the switch from the old to the new energy labels by implementing the new labeling regulation on the refrigerators portfolio available in February 2021. In panel (2), we consider the effect of banning products with energy labels F and G, by reclassifying them as label E in March 2021. In panel (3), we assess the impact of introducing a feebate system in March 2021, which subsidizes energy-efficient products and taxes less efficient ones. As a robustness check, we also consider the first two scenarios using the *labels* specification, which are reported in Table B.3 in the Appendix.

Table 6: Changes in average electricity usage per refrigerator

Country	kWh before	kWh after	Change (%)	Price change (%)
(1) Switch from old to new labels				
Country	kWh before	kWh after	Change (%)	Price change (%)
Belgium	203	199	-1.8	0.0
France	259	258	-0.7	0.0
Germany	204	199	-2.2	0.0
Poland	253	248	-1.9	-0.3
(2) Banning new F and G labels				
Country	kWh before	kWh after	Change (%)	Price change (%)
Belgium	199	174	-12.7	8.7
France	253	214	-15.5	9.4
Germany	203	184	-9.6	6.4
Poland	259	224	-13.5	8.4
(3) Feebate (correction for internality)				
Country	kWh before	kWh after	Change (%)	Price change (%)
Belgium	199	190	-4.7	0.1
France	253	245	-3.4	0.0
Germany	203	195	-4.3	0.0
Poland	259	254	-1.8	-0.1
(4) Feebate + (correction for internality and externality)				
Country	kWh before	kWh after	Change (%)	Price change (%)
Belgium	199	187	-6.0	0.1
France	253	242	-4.5	0.0
Germany	203	191	-6.0	0.0
Poland	259	250	-3.2	-0.2

Counterfactual (1) is conducted for the last month of the old regulation (February 2021), and counterfactuals (2), (3), and (4) for the first month of the new regulation (March 2021).

Impact of New Energy Labels The first scenario evaluates what would have happened to average energy consumption if the new labeling regime had been introduced on the refrigerator portfolio available in February 2021, when products still displayed the old labels. In general, the introduction of a new label system can reduce energy consumption in two ways: from improved consumer awareness—if the clearer labeling prompted households to choose more efficient refrigerators—or from manufacturers upgrading their product portfolios to meet stricter efficiency requirements. Our counterfactual, therefore, aims to isolate the pure effect of the label change through consumer awareness rather than through changes in the product mix driven by manufacturers.

We implement this scenario by predicting the new energy labels for all products sold in February 2021 using a random forest model trained on product characteristics and energy consumption.[12] For the existing product portfolio, we then replace the old labels with their predicted new-label equivalents, thereby simulating how these products would have been presented had the new labeling regulation been introduced earlier. The reassigned labels are subsequently used to recompute consumer valuations, capturing how the new system might have influenced purchasing decisions before its actual implementation. All other product attributes—including energy consumption and marginal costs—are held constant to isolate the pure effect of the label change.

We find that the new energy label system would reduce the average energy consumption of purchased refrigerators in all countries: by –1.8% in Belgium, by –2.2% in Germany, by –1.9% in Poland, and only slightly by –0.7% in France. This improvement is driven by the relocation of sales towards more energy-efficient refrigerators, as shown in Table 7. For example, in Belgium, the market share increases by 6 percentage points for E labels (from 32% to 38%), whereas it drops by 8 percentage points for F labels (from 53% to 45%); the changes are small for the other labels. Similar findings are obtained for the other countries.

Banning New F and G Labels The second scenario—banning products with labels F and G—represents a stricter regulatory intervention aimed at accelerating the removal of low-efficiency models from the market. As discussed above, we do not simply remove products with labels F and G, as doing so would reduce product variety. Instead, we replace all refrigerators originally labeled F or G with otherwise identical models relabeled as E.

Operationally, we implement this counterfactual by adjusting both demand and cost components. On the demand side, we substitute the average energy cost associated with labels F and G with the corresponding average energy cost for label E in consumer utility. On the supply side, we update marginal costs and energy usage for the affected products accordingly. Because E-label models are more energy efficient, these adjustments imply—according to our estimates—both an increase in consumer valuation and higher marginal production costs.

12. As discussed in Section 4, the algorithm achieved a 99% in-sample prediction accuracy for cases where both old and new labels were known.

The magnitudes of these adjustments are derived from the demand regression (Table 3) and from the marginal cost regression (Table 5). Accordingly, for all products originally assigned to labels F or G, we replace their energy consumption and marginal cost values with the estimated counterparts for label E.

According to Table 6, replacing refrigerators with labels F and G with models labeled E leads to a substantial reduction in energy consumption: 15.5% in France, 13.5% in Poland, 12.7% in Belgium, and 9.6% in Germany. These improvements are much larger than the impact of the new labels, shown in the previous counterfactual. Table 7 shows the shifts in market shares responsible for this improvement: a large share of consumers substitute from categories F and G to E. For example, in Belgium, the market share of E labels increases from 32% to 91%. Similarly large shifts to the E labels occur for other countries. Note that a small number of consumers from top categories C and D substitute for E labels.

Feebate Finally, as discussed in Section 5.1, the third scenario implements a feebate policy designed to correct both for the internality arising from consumers' undervaluation of electricity costs when purchasing refrigerators, and for the emission externality per euro of lifetime electricity expenditure (over 15 years). Recall that a feebate is defined as:

$$t_{lc} = \tau_c \left(G_{lc} - \tilde{G}_c \right), \tag{9}$$

where $\tau_c = 1 - \gamma_c + \psi$ is the *feebate rate* and $\tilde{G}_c$ denotes the pivot point. Products with lifetime energy costs above $\tilde{G}_c$ are taxed, while those below it receive a subsidy.

The feebate rates that correct for the internality are based on our undervaluation estimates γ_c in Table 3, amounting to rates of 58% in France (the highest undervaluation), 53% in Belgium, 40% in Germany, and 21% in Poland (the lowest undervaluation). The additional feebate rate to correct for the emissions externality (ψ) is set to 15%, assuming a social cost of carbon of 100 euros per ton of CO_2 and that natural gas, rather than coal, is the marginal generation technology in the electricity mix.

In this simulation, we adjust consumer utility to reflect these incentives, while keeping the product portfolio unchanged. Feebates, therefore, automatically preserve product variety, allowing producers to internalize environmental costs and consumers to respond to efficiency-based price signals. As shown in Table 6, under the first feebate scheme, which corrects only for the internality, average energy use declines by 4.7% in Belgium, 4.3% in Germany, 3.4% in France, and 1.8% in Poland. Under the second feebate scheme, which additionally accounts for the externality associated with the social cost of CO_2 emissions from electricity consumption, the resulting energy savings increase to 6.0% in Belgium, 6.0% in Germany, 4.5% in France, and 3.2% in Poland.

These reductions are driven by a reallocation of consumers from less energy-efficient to more efficient labels, as shown in Table 7. The market shares of labels F and G decline but remain positive, in contrast to the previous scenario in which these labels are banned entirely. For example, in Belgium, the second feebate scheme reduces the market share of label F from 53% to 35% and that of label G from 5% to 2%. At the same time, the market shares of more efficient labels increase. In particular, the shares of labels D and C rise from 8% to 15% and from 2% to 4%, respectively. Overall, while feebates generate more moderate improvements in energy efficiency than an outright ban of F and G labels, they are likely to impose smaller adjustments on consumers and firms. In addition, by construction, the policy remains approximately revenue-neutral.

Table 7: Shares by Label Under Counterfactual Policies

		Belgium			
Label	Base	(1) Old to New	(2) Ban F/G	(3) Feebate	(4) Feebate +
C	2%	3%	2%	3%	4%
D	8%	9%	7%	13%	15%
E	32%	38%	27%	42%	44%
F	53%	45%	60%	40%	35%
G	5%	6%	4%	2%	2%
		France			
Label	Base	(1) Old to New	(2) Ban F/G	(3) Feebate	(4) Feebate +
C	0%	1%	0%	1%	2%
D	3%	4%	3%	6%	7%
E	23%	27%	22%	34%	36%
F	67%	63%	72%	54%	51%
G	7%	5%	3%	5%	4%
		Germany			
Label	Base	(1) Old to New	(2) Ban F/G	(3) Feebate	(4) Feebate +
C	5%	5%	5%	9%	10%
D	13%	16%	11%	20%	23%
E	40%	45%	34%	42%	42%
F	39%	31%	49%	28%	24%
G	3%	3%	2%	2%	1%
		Poland			
Label	Base	(1) Old to New	(2) Ban F/G	(3) Feebate	(4) Feebate +
C	3%	3%	2%	4%	5%
D	10%	11%	8%	12%	14%
E	27%	36%	21%	30%	31%
F	52%	45%	63%	47%	44%
G	8%	5%	7%	7%	6%

Base is March 2021. Counterfactual (1) is conducted for the last month of the old regulation (February 2021), and counterfactuals (2), (3), and (4) for the first month of the new regulation (March 2021). Feebate corrects for internality only, whereas feebate + additionally corrects for externality.

8 Conclusion

This paper examines changes in the annual energy consumption of refrigerators sold in Belgium, France, Germany, and Poland between 2019 and 2022, with a focus on the impact of the 2021 EU energy labeling reform. The analysis combines descriptive and reduced-form evidence, structural demand estimation, and counterfactual policy simulations.

Our descriptive results reveal substantial cross-country variation in the sales-weighted energy consumption of refrigerators. Belgium and Germany consistently exhibit a lower average energy use—reflecting the composition of their product portfolios and consumer preferences—whereas consumers in France and Poland tend to purchase less efficient models. Following the introduction of the new EU energy labels in March 2021, average energy consumption declined in all four countries. Accounting for product characteristics, the reductions are meaningful: between roughly 3.3% in France and 4.2% in Belgium.

To explore this further, we estimate two nested logit demand specifications. The first directly includes labels in consumer utility, whereas the second incorporates the expected discounted 15-year electricity cost per energy label.

The results from the first specification reveal a clear and robust ranking of preferences across energy labels. In all countries, consumers are willing to pay more for refrigerators with higher energy efficiency. Thus, energy labels play an important role in shaping perceptions of product quality and operating costs. While the normalization of utility for the least efficient labels prevents an absolute comparison between willingness to pay and lifetime electricity savings, the relative structure of the estimates is nonetheless informative. Differences in WTP across labels can be contrasted with corresponding differences in expected energy expenditures, providing first insights into how consumers trade off upfront prices against future operating costs. The results suggest that consumers do account for electricity costs when choosing refrigerators, but that these costs are systematically undervalued relative to their full economic impact, which is consistent with the estimates of the second specification.

The results from the *electricity cost* specification provide more conclusive information based on additional structure. They reveal that consumers in France and Belgium substantially undervalue future electricity costs under both the old and new labeling regimes, with some improvement under the new regulation. The degree of undervaluation is smaller in Germany and the lowest in Poland. Several mechanisms may help explain these cross-country differences in undervaluation. First, electricity prices vary considerably across the four countries. In Poland, where the electricity burden relative to household income is higher, consumers may pay more attention to operating costs than in France or Belgium. Second, survey evidence suggests substantial heterogeneity in energy awareness: Polish consumers are more likely to report purchasing energy-efficient appliances to reduce energy use, whereas French households express a comparatively low concern for household energy savings. Third, computing long-run electricity costs requires an effort, and consumers in some countries may rely more heavily on brand reputation rather than performing a detailed cost calculation. For example, in Germany, local brands are generally more energy-efficient and are preferred by consumers.

Using the estimated model, we analyze three counterfactual policy interventions. First, we consider the direct impact of the new labeling regulation through an early implementation in February 2021 by assigning the predicted new labels to all products sold at that time. Under this counterfactual, the average energy consumption per refrigerator sold declines modestly but consistently across countries. Second, we simulate the impact of a regulatory ban on the least energy-efficient refrigerators by replacing all products labeled F and G with otherwise comparable models assigned to label E. This intervention generates large reductions in average energy consumption. Third, we evaluate a market-based feebate scheme that taxes inefficient refrigerators while subsidizing more efficient ones. This policy generates intermediate reductions in average energy use. The reduction increases when additionally accounting for externalities associated with electricity consumption. Although an outright ban of the worst labels would imply larger emission savings, it also results in much higher consumer prices.

These results reveal substantial cross-country heterogeneity in both consumer behavior and the effectiveness of policy interventions. While the new EU labeling scheme has improved the average energy efficiency of refrigerators purchased in all four countries, the effects remain relatively modest. Persistent consumer undervaluation of operating costs suggests that complementary informational, regulatory, or fiscal measures may be required to fully realize the potential of labeling reforms. In particular, a feebate policy designed to correct consumer misperceptions produces meaningful efficiency gains, while eliminating inefficient labels generates substantially larger reductions in energy consumption, but at the cost of higher prices. Differences in electricity prices, product availability, and consumer preferences across countries further emphasize the importance of tailoring energy-efficiency policies to national market conditions.

To our knowledge, this is the first paper to jointly evaluate informational labels, minimum energy efficiency standards, and feebate policies within a unified structural demand–supply framework using detailed European product-level sales data.

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Appendix A

A.1 Energy Labels of Refrigerating Appliances

The new energy efficiency class of refrigerating appliances is determined based on the Energy Efficiency Index (EEI), as shown in Table A.1. The EEI calculation has changed and become stricter after March 2021.

The first step in calculating the Energy Efficiency Index (EEI) is to measure the annual energy consumption in kWh/annum, denoted as

$$AE_C = \frac{365 \times E_{24h}}{L},$$

where $E_{24h} = 0.5 \times (E_{16} + E_{32})$ represents the energy consumption measured over 24 hours at ambient temperatures of 16 °C and 32 °C in a test room, respectively. The load factor L is set to 0.9 for refrigerating appliances with only frozen compartments and 1.0 for all other appliances.

The measurement should include the energy consumed during normal operation, including any defrosting cycles. The appliance should be tested when it is empty. The reported value shall not be greater than the measurement by more than 10%.

Table A.1: The Energy Efficiency Index (EEI)

Old Label	**Old EEI Range (%)**	**New Label**	**New EEI Range (%)**
A+++ A++ A+	EEI $<$ 22 22 $\leq$ EEI $<$ 33 33 $\leq$ EEI $<$ 42	A	EEI $<$ 41
A	42 $\leq$ EEI $<$ 55	B C	41 $\leq$ EEI $<$ 51 51 $\leq$ EEI $<$ 64
B	55 $\leq$ EEI $<$ 75	D	64 $\leq$ EEI $<$ 80
C	75 $\leq$ EEI $<$ 95	E	80 $\leq$ EEI $<$ 100
D E	95 $\leq$ EEI $\geq$ 110 110 $\leq$ EEI $\geq$ 125	F	100 $\leq$ EEI $<$ 125
F G	125 $\leq$ EEI $\geq$ 150 EEI $\geq$ 150	G	EEI $\geq$ 125

The Energy Efficiency Index (EEI) of household refrigerating appliances is calculated as:

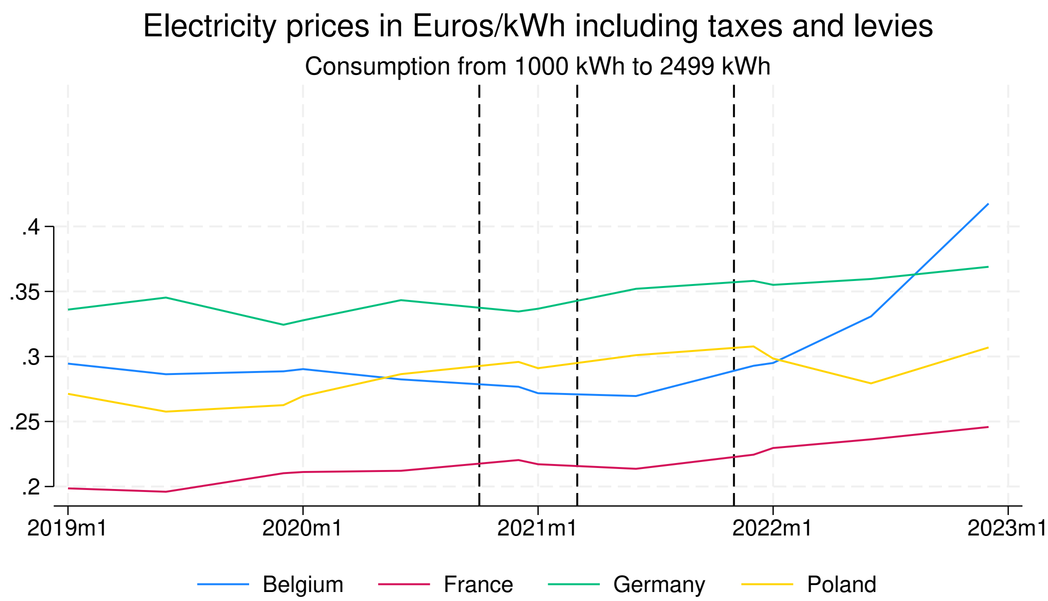
$$EEI = \frac{AE_C}{SAE_C} \times 100$$

where $SAE_C = C \times D \times \sum_{c=1}^{n} A_c \times B_c \times \left[\frac{V_c}{V}\right] \times (N_c + V \times r_c \times M_c)$ represents the standard annual energy consumption (kWh/annum), where: (i) V_c is the volume (dm^3) of compartment $c = 1, \ldots, n$, (ii) V is the total volume (dm^3), and (iii) the remaining terms $(C, D, A_c, B_c, N_c, r_c, M_c)$ are modeling parameters and compensation factors.

A.2 Electricity prices

In this section, we discuss the development and regulation of electricity prices in the four countries considered in this analysis. The corresponding price levels in Euros PPP per kWh are presented in Figure A.1.

Figure A.1: Electricity prices in the four countries.



Belgium: The retail electricity market is liberalized with prices determined by suppliers but including regulated components such as network tariffs and levies. In response to the sharp rise in energy prices in 2021–2022, the federal government implemented several relief measures. On 1 February 2022, it was announced that all households with a residential electricity contract would receive a one-time rebate of €100, applied directly as a deduction on their electricity bills. The rebate was automatically credited on bills issued between 18 April and 31 July 2022, reaching approximately 4.1 million households out of an estimated 4.9 million eligible beneficiaries.

In addition, the government temporarily reduced the value-added tax (VAT) on electricity from 21% to 6%, and extended the eligibility criteria for the "social tariff"—a subsidized tariff set at the lowest market price—to include a larger share of vulnerable households. These measures complemented existing regional support schemes and were designed to mitigate the impact of the global energy crisis on consumers.

France: In France, residential electricity consumers can opt for a regulated sales tariff (*Tarif Réglementé de Vente*, TRV), overseen by the government and set on the recommendation of the Energy Regulation Commission (CRE). In response to surging wholesale prices during the energy crisis, the government introduced a comprehensive "tariff shield" (*bouclier tarifaire*) starting in October 2021, which effectively limited increases in regulated tariffs. This was implemented through a combination of measures: a sharp reduction in the main tax on electricity (TICFE), from around €22.50/MWh to €0.50–€1.00/MWh for households; an increase in the annual volume of "regulated access to historic nuclear electricity" (*Accès Régulé à l'Électricité Nucléaire Historique*, ARENH) from 100 to 120 TWh to give alternative suppliers access to lower-cost nuclear generation; a compensation scheme for electricity and gas suppliers to cover the gap between wholesale procurement costs and retail tariff revenues; and a legal obligation for incumbent suppliers of regulated tariffs (EDF for electricity, Engie for natural gas) to limit tariff increases to 4% in 2022 instead of the much larger increases implied by market conditions. These price-control measures were complemented by targeted subsidies to households. First, an additional "energy cheque" of €100 was granted to the approximately 5.8million low-income households already eligible for the regular annual energy cheque. Second, a one-off €100 "inflation allowance" (*indemnité inflation*) was paid to about 38million people with incomes below a certain threshold.

Germany: In Germany, retail electricity prices for households are not directly regulated. Instead, they are determined by market dynamics, although they include several regulated components such as grid fees, taxes, and surcharges. Between 2019 and 2021, household electricity prices remained in the low range of 30 euro cents/kWh on average. In 2020, the average price was approximately 31.5 euro cents/kWh, with a significant share made up of politically controlled elements like surcharges and taxes.

In mid-2022, the Renewable Energy Surcharge (*EEG-Umlage*)—which had accounted for about 3.72 euro cents/kWh—was abolished, which partially offset the upward pressure on retail prices caused by rising procurement and wholesale costs. Nevertheless, by late 2022, average retail prices for households had risen sharply to around 40.1 euro cents/kWh, mainly due to the energy crisis and wholesale market volatility.

In September 2022, the federal government announced an electricity price cap as part of its "protective shield" measures. Under this policy, household electricity prices were capped at 0.40 euro/kWh for 80% of annual consumption, with usage above this threshold billed at market rates. These measures were formalised in the Electricity Price Control Act (*StromPBG*) passed in December 2022, and were financed in part through the collection of surplus profits from energy generators.

Poland: In the Polish electricity tariff system, separate prices are set for household (residential) customers and for commercial or industrial users. In 2021, there were about 15.5 million residential consumers, with an average annual electricity consumption of about 2,000 kWh. Residential customers are subdivided into tariff types based on the time-of-use pricing structure.

The most common tariff, G11, is a single-zone (flat-rate) tariff in which the price per kilowatt-hour is constant throughout the entire day and night. This tariff accounts for around 87% of all residential customers (about 13.5 million), with average annual consumption of approximately 1,800 kWh. The second most common tariff, G12, is a two-zone (time-of-use) tariff in which electricity is billed at two different rates: a higher day rate and a lower night (and sometimes off-peak) rate, intended to encourage shifting consumption to cheaper hours. Households in this group have a higher average consumption—about 3,200 kWh per year—often because they use electricity-intensive appliances (e.g., electric heating or water heating) during off-peak hours.

During the period 2019–2021, all household electricity tariffs remained regulated and suppliers were required to apply these regulated rates. In response to the surge in energy prices in 2021–2022, partly triggered by the energy crisis and high inflation, the government implemented the *Anti-Inflation Shield*, which included a reduction of VAT on electricity from 23% to 5% (effective from January 2022) and temporary exemptions from excise duty for households, but did not involve tariff freezes.

Starting from 1 January 2023, the government introduced further extraordinary measures under the *Act on Special Solutions for the Protection of Electricity Consumers*, especially targeting households consuming up to 2,000 kWh annually (higher thresholds applied to larger families and households with persons with disabilities). For eligible households, retail electricity prices were capped at the 2022 tariff levels approved by URE and frozen for the entire year. Consumption above the threshold was billed at a higher, but still capped, statutory maximum price. Suppliers were reimbursed for the difference via state compensation.

A.3 Social costs from energy emissions

To calibrate the externality component ψ, we follow the logic of feebate schemes in the automobile literature, adapted to electricity consumption. Let s denote the social cost of carbon (in euros per kg of CO_2), and let κ denote the emission intensity of electricity generation (kg of CO_2 per kWh). The social cost of electricity consumption per kWh is then $s \cdot \kappa$. Because G_{lc} is measured in euros of lifetime electricity expenditure, the externality correction must be expressed per euro of electricity cost. The externality tax rate is therefore given by:

$$\psi = \frac{s \cdot \kappa}{g},$$

where g denotes the electricity price per kWh. Intuitively, ψ equals the social cost of electricity per kWh relative to the electricity price per kWh.

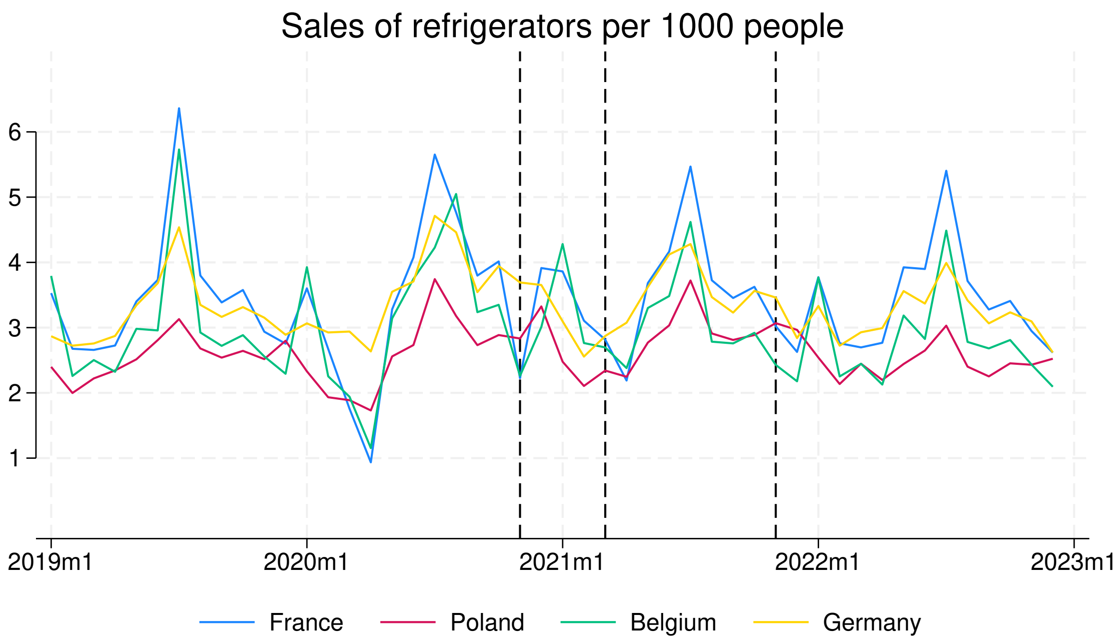
As a numerical benchmark, consider a social cost of carbon of 100 euros per ton of CO_2 ($s = 0.1$ euros per kg), an emission intensity of $\kappa = 0.45$ kg CO_2 per kWh (natural gas), and an electricity price of $g = 0.30$ euros per kWh. This implies an externality tax rate of $\psi \approx 0.15$. Under a coal-based electricity mix with $\kappa = 0.82$, the implied tax rate would be approximately $\psi \approx 0.27$.[13]

13. As of January 2026, the projected market-driven price of carbon in the European Union (EU) Emissions Trading System (ETS) is expected to range between 80 euros and over 100 euros per ton of CO_2. Coal-fired power plants emit around 820g of CO_2 per kWh, while natural gas emits around 450g of CO_2 per kWh.

Appendix B

B.1 Descriptive statistics and estimations

Figure B.1: Sales of refrigerators in thousands (with trade brands)



The population is fixed for 2018 as follows: Belgium (11.43 million), France (67.16 million), Germany (82.19 million), and Poland (37.97 million).

Table B.1: Annual energy consumption regression

Variables	Coeff	Litres	Depth	Width	Height
Main type 1	-0.0102	-0.0155	-0.0265	-0.5119***	0.4955***
	(0.396)	(0.038)	(0.063)	(0.133)	(0.047)
Main type 2	-1.9918	0.3065***	-0.0130	0.6067**	-0.3971***
	(1.514)	(0.081)	(0.189)	(0.307)	(0.107)
Main type 3	3.3138***	0.7534***	-0.5730***	-0.0244	-0.8286***
	(0.316)	(0.033)	(0.045)	(0.068)	(0.053)
Main type 4	-1.4416***	0.4672***	-0.3948***	0.4787***	-0.2127**
	(0.501)	(0.067)	(0.075)	(0.126)	(0.093)
Main type 4	-0.8447	0.3680***	0.1502	0.3549***	-0.4531*
	(1.466)	(0.074)	(0.122)	(0.108)	(0.238)
Main type 5	-7.6185**	0.2302***	0.0020	-0.3168***	1.7214***
	(3.041)	(0.064)	(0.105)	(0.111)	(0.644)
Freezer bottom	0.0172				
	(0.029)				
Freezer top	0.3814***				
	(0.006)				
Freestanding	-0.0954***				
	(0.017)				
Stars	0.0130***				
	(0.004)				
Drawers	0.0036				
	(0.009)				
Temp. control	-0.0838***				
	(0.005)				
Water dispenser	0.1002***				
	(0.012)				
Water container	-0.0463***				
	(0.013)				
Water direct	-0.0454***				
	(0.013)				
Icecube dispenser	-0.0254**				
	(0.013)				
Crushed ice	0.0266**				
	(0.013)				
Chiller zone	-0.0522***				
	(0.006)				
Ventilated air	-0.0237***				
	(0.004)				
Mounting door	-0.0383**				
	(0.015)				
Mounting slide	-0.0020				
	(0.015)				
Display	-0.0508***				
	(0.004)				
Smart connect	-0.0341***				
	(0.009)				
Nofrost	0.1265***				
	(0.006)				
Full nofrost	0.0390***				
	(0.005)				
Led light	-0.0101***				
	(0.004)				
Inverter motor	-0.1092***				
	(0.006)				
Cooling	0.0601***				
	(0.007)				
Cooling compressor	0.0072*				
	(0.004)				
Fullbody steel	0.0348**				
	(0.014)				
Deco dummy 1	-0.0263				
	(0.019)				
Deco dummy 2	-0.0363*				
	(0.019)				
Deco dummy 3	-0.0030				
	(0.019)				
Constant	4.6585***				
	(0.017)				
Observations	16,678				
R-squared	0.847				

Table B.2: Labels vs. Electricity Cost Specifications: common parameters

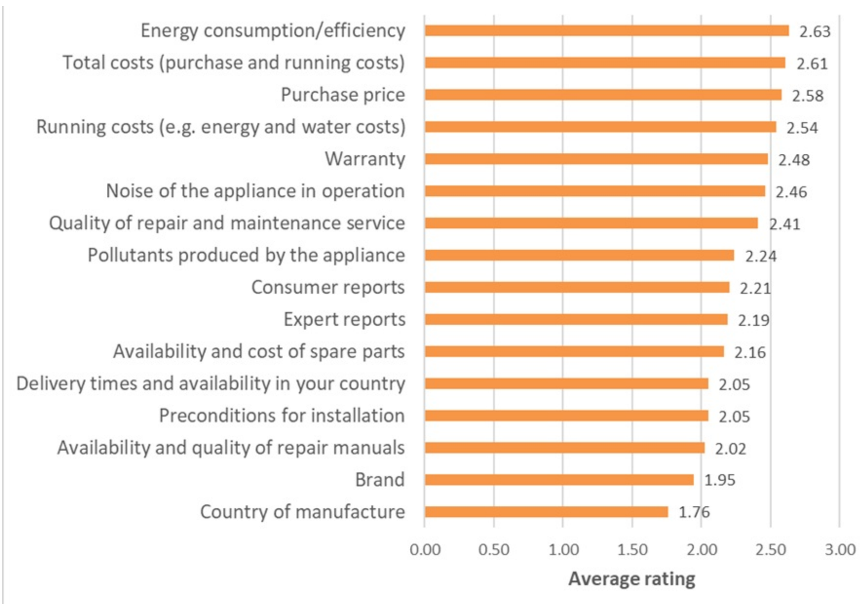
	Labels	**Electricity cost**
sigma	0.8422***	0.6828***
	(0.022)	(0.018)
Freestanding dummy	-1.4073***	-1.1487***
	(0.049)	(0.043)
log(noise in Db)	-1.2635***	-2.0626***
	(0.105)	(0.078)
Freezer stars	-0.1373***	-0.1359***
	(0.011)	(0.010)
Deco A	-0.1424***	-0.1152***
	(0.036)	(0.034)
Deco B	0.3343***	0.2868***
	(0.018)	(0.016)
Deco C	0.3450***	0.2245***
	(0.025)	(0.021)
Temperature control	0.2892***	0.1889***
	(0.025)	(0.021)
Full nofrost	0.0576***	0.0427***
	(0.012)	(0.011)
Led light	0.1118***	0.1697***
	(0.010)	(0.011)
Icecube dispenser	0.8031***	0.4687***
	(0.079)	(0.064)
Smart connect	1.1534***	0.8453***
	(0.079)	(0.065)
Observations	91,204	91,204
R-squared	0.799	0.814

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table B.3: Counterfactual Policy Simulations (*labels* specification)

(1) Switch from old to new labels			
Country	Before	After	Change
Belgium	203	196	-3.1%
France	259	253	-2.7%
Germany	204	191	-6.4%
Poland	253	231	-8.8%
(2) Banning new F and G labels			
Country	Before	After	Change
Belgium	199	175	-12.0%
France	253	215	-15.2%
Germany	203	184	-9.3%
Poland	259	224	-13.3%

Figure B.2: Most important aspects when purchasing household appliances



Note: Average importance rated 0–3 (higher = more important). Source: EPREL Services survey, 2025.

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