Do Labels Matter? Evaluating the Implications of New Energy-Efficiency Labels*

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PRELIMINARY AND INCOMPLETE! PLEASE FO NOT CITE!!!

Abstract

The energy efficiency classes and the corresponding labeling policy in the European Union have been overhauled in March 2021. In this paper, we use data from cold appliances market in Germany between the years 2019 and 2022 to investigate the implications of this policy change. We first construct some descriptive measures of the purchased refrigerators. Our findings indicate that beyond a cosmetic change in the energy labels of the purchased products, no substantial change in the annual energy consumption of the purchased models can be seen. We then use reduced form regression models to understand the determinants of refrigerator prices in Germany. We find that refrigerators which have higher volume, are built in/under, have ventilated air functionality and seperate temperature functionality are more expensive. Both before and after the change in the labeling framework, refrigerators with labels associated with higher effieciency are more expensive. Noise levels and led lighting seem to have mixed effects on prices. Most puzzling effect we find involves a positive coefficient on the annual energy consumption on large refrigerators. We believe this is an artifact of our regression model which includes three interdependent variables: volume, annual energy consumption and the energy label.

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1 Introduction

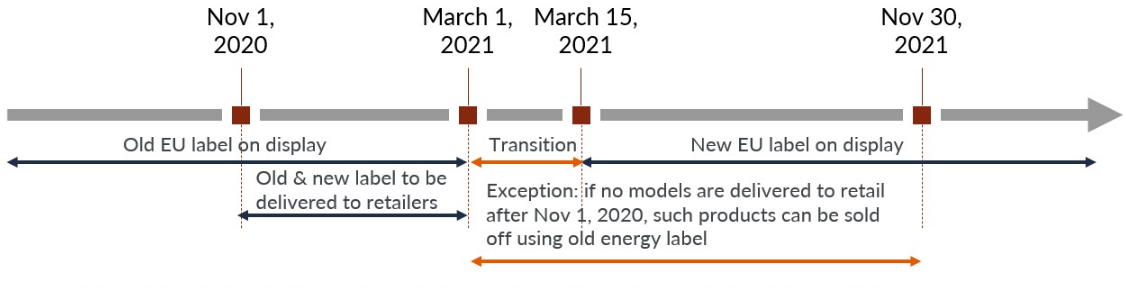
In response to the urgent need to combat climate change, the European Union (EU) targets achieving carbon neutrality by the middle of this century. The transition to cleaner and more energy-efficient sources is guided by a package of policy initiatives called the European Green Deal. Implementing various directives and regulations, this strategy aims to improve energy efficiency, and eco-design of products and to alleviate energy poverty.

At the heart of the EU's initiatives to reduce energy consumption in household appliances and industrial machines are the Energy Labeling Regulation and the Ecodesign Directive. The former requires products to display an energy efficiency label, while the latter sets minimum energy efficiency standards for specific products, excluding less efficient ones from the EU market. Additionally, energy efficiency building standards have been a common policy tool in Europe for over four decades.

The EU's regulations on energy efficiency are crucial, given that end-use energy efficiency could reduce global CO2 emissions by about 35% by 2050, despite a projected significant increase in the world's GDP. Within the EU, household appliances are responsible for roughly 25% of total energy consumption, with a significant impact on greenhouse gas emissions (see Russo et al., 2018). Therefore, it is vital to focus on the adoption of energy-efficient technologies in households and design policies that promote such´ technologies.

In this paper, we contribute to this literature by assessing the welfare effects of the EU's Energy Labeling Regulation. In March 2021, a new EU labeling framework, which was updated and adopted by the Regulation (EU) 2017/1369 of 4 July 2017, came in effect. This new framework introduces a simpler classification, using only the letters from A to G, which replaced the previous A+++, A++, and A+, A, B, C, and D categories. According to the Commission, it improves the differentiation among products that, under the old label classification, appeared in the same top categories. The main principle of the new framework was that the A category was empty at first, and the B and C categories were scarcely populated, which should stimulate innovation and the development of new more energy-efficient products. As of 1st March 2019, product categories including dishwashers, washing machines, refrigerators, and electronic displays had to be sold with new energy labels and old labels had to be replaced after a short transition period of 2 weeks. There can be some rare exceptions, like when a product model is discontinued then the model that is already on shelves in the shop can keep its old label.

Figure 1: Timeline of Old and New EU Labeling Regulation



In this paper, we will explore the implications of this new labeling framework for the market for refrigarators in Germany. Refrigarators by their nature are one of the most energy demanding appliances in a household as they need to be continuously plugged in. According a report by BDEW, and industry association, refrigerators have accounted for about %25 of the electricity consumption in a household. (BDEW (2019) Given that households account for roughly %26 of the electricity consumption in the country (Statista 2024), refrigerators certainly contribute a substantial amount to energy consumption. Thus, understanding whether improved labeling can nudge consumer choices in the direction of higher energy efficiency is an important exercise in assessing the effectiveness of new policy initatives.

We aim in this study is to understand determinants of refrigerator prices and consumption in Germany in the recent years. For this purpose, we will use a dataset that contains monthly sales and price information along with model characteristics for the refrigerator market in Germany for the years between 2019 and 2022. Fortunately, this period includes the introduction of the new labeling framework in March 2021. Using this data, we want achieve a number of objectives. First, we would like to describe the developments in the market in this period, and document the evolution of the energy use of purchased refrigerators and their prices. Second, we would like to understand the determinants of the refrigerator prices using reduced form econometric models with a special attention to the role of energy labels. We believe this to be an essential input to more elaborate structural models of refrigerator demand which we intend to pursue in future research.

Our descriptive analysis of the data indicate that the new labeling framework unfortunately has not resulted in a substantial change in the annual energy consumption of an average refrigerator purchased in Germany. We do find a positive change in the shares of more efficiency classes which are considered better, but this seems to be a cosmetic change. Thus, our initial verdict is in the direction of no substanstial effect of the new labels in the efficiency properties of the purchased refrigerators.

We then explore the determinants of the refrigerator prices using reduced form models. These models not only give a first indication about important factors influencing the prices, but also will serve as a good starting point for more elaborate stuctural models which we intend to pursue in subsequent research. Many of the parameters we consider yield intutive and robust estimates. We find that freestanding refrigerators will be on average cheaper. Another rather intuitive finding indicates that the larger the volume of a refrigerator, the more expensive it would be. Characteristics such as ventilated air functionality and seperate temperature control seem to positively impact the prices. We find mixed results for noise levels and led lightning.

The most puzzling finding involves positive estimates of annual energy consumption coefficient for large refrigerators. This finding seem to be robust accross different refrigerator types we study. We think that this finding is an artifact of the our modeling choices where we include volume, annual energy consumption and energy labels—three interdependent variables—in the same regression. This finding requires further study to understand the possible mechanisms that may yield such counterintuitive parameter estimates.

The remainder of the paper is organized as follows. Section 2 describes the institutional background pertinent to energy-efficiency regulations. Section 3 reviews the relevant literature. Section 4 introduces our dataset, and presents a number of descriptive analysis of the data. In section 5, we introduce a reduced form empirical model to explore the determinants of prices. And, finally Section 6 concludes.

2 Institutional Background

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 "A" was no longer enough to describe the most energy-efficient products. At the same time, the lower classes (E, F, G) for some product categories were phased out due to ecodesign requirements or became so rare that they were no longer needed. This directive introduced new energy efficiency classes A+, A++, and A+++, and 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 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 2017/1369/EU from July 2017. This is the new labeling frameowrk that we wish to evaluate in this paper. This update introduced a simpler classification system, using only the letters A to G. This change was intended to enhance differentiation among products that, under the 2010 EU Energy Label, appeared in the same top categories. For instance, a refridgerator previously labeled A+++ could be reclassified as B, C, D, or E under the new system. The primary aim of this regulation was to initially leave the A category empty and sparsely populate the B and C categories. This strategy was designed to encourage the invention and development of new, more energy-efficient products.

The Energy Labeling Regulation is complemented by the Eco-design Directive 2009/125/EC, which establishes a framework to set mandatory ecological requirements for energy-using and energy-related products sold in the EU. Manufacturers who begin marketing an energy-using product covered by this regulation have to ensure that it conforms to the required energy and environmental standards. The introduction of a minimum requirement results in effectively banning all non-compliant products from the EU market. The Eco-design Directive, in conjunction with the Energy Labeling Regulation, seeks to bring more efficient products to the market, create fair competition among manufacturers, and empower consumers to make informed, energy-efficient choices.

The new regulation changes a number of definitions and formulas regarding how the new energy eficiency classes/labels are to be determined. The new label for a refrigerator, as the old one, depends on a construct called energy efficiency index (EEI). EEI is computed as the percentage of the reported annual energy consumption(AEC) of a refrigerator to a standardized annual energy consumption(SAE) of a refrigator with similar volume and properties. Namely, the energy efficiency index is given by

$$EEI = \frac{AEC}{SAE} \times 100.$$

Interestingly the new framework introduces changes in the calculation of both the numerator and denominator of this measure. The construction of the new measure is described in detail in European Commision (2019). Similarly, the regulation which described the framework until the change in March 2021, can be found in European Commision (2010).

There are a few important changes to consider. Most importantly, the calculation of the annual energy consumption of an appliance takes the average of annual enerygy consumption in two different outside temperatures, while the earlier calculation did not stipulate to an outside temperature. This clearly implies that some refrigerators which remain in the market may change their reported annual energy consumption. Moreover, the new regulation European Commision (2019) allows producers a %10 error margin. Namely, the reported annual energy consumption of an appliance is allowed to deviate from the measured consumption by at most %10 percent. This possibility of deviation between measured and reported AEC levels resulted in quite an interesting dynamic in the reported AEC levels. The standardized annual energy consumption level also changed in its calculation which further makes it possible that refrigerators which are sold before and after the introduction of the new framework may experience significant changes in their AEC levels.

These changes also resulted in situations where two refrigerators which had the same labels prior to the introduction of the new framework, can end up with different labels in the new framework. On the other hand, it is also possible that two refrigerators which end up having the same labels under the new framework, may have had different labels prior to March 2021. We believe understanding and documenting these dynamics is essential in understanding the changes unleashed by the new labeling framework.

[To be expanded]

3 Literature Review

An important group of actors which will play perhaps a leading role in the success of the European Green Deal are the consumers. Ultimately, their behavior in adopting energy-efficient appliances, living in energy-efficient residences, and driving energy-efficient vehicles will determine whether CO2 emissions due to household consumption will decline. There exists a large stream of literature assessing consumer responses to energy saving policies, as surveyed in Gerarden et al. (2017) and Gillingham et al. (2018). The cautionary message which emerges from this literature is that there is a so-called "energy-efficiency gap" in adopting energy-efficient technologies in a variety of domains ranging from household appliances, building weatherization measures and vehicles, among others. Gerarden et al. (2017) list three potential explanations for the observed gap. These are (i) market failures due to information problems and liquidity constraints; (ii) behavioral anomalies: inattentiveness and salience issues, myopia, bounded-rationality, systematically biased beliefs; and (iii) model and measurement errors. Interestingly, many of the papers which are prominently published and presented in this survey attempt to explain this gap by means of behavioral anomalies.

Gillingham et al. (2018) not only review the literature on the causes of the energy-efficiency gap but also the effectiveness of policies which aim to increase the adoption of energy-efficient technologies. Such policies can be classified into four broad groups: (i) non-price behavioral interventions, (ii) subsidies for adoption of efficient products and technologies, (iii) minimum efficiency standards and (iv) informative policies such as labeling. As they note, the ideal setting for evaluating any of these policies will involve a randomized controlled trial (RCT) or a field experiment. Even though some papers use RCTs (e.g. Allcott and Taubinsky (2015) or Allcott and Knittel (2019)), they are not used at scale due to the difficulties arising from implementing such experiments – in particular, their cost and the need for cooperating partners in the industry. Instead, many researchers combine observational data, natural experiments and clever identification strategies to assess effectiveness of policies which aim to increase adoption of energy-efficient technologies.

Unlike other EU regulations that set standards for energy efficiency—e.g. Ecodesign Directive or Energy Performance of Buildings Directive, the effectiveness of the Energy Labeling largely depends on the extent to which it can significantly influence consumers' decision making process. The degree of this influence crucially depends on two interrelated factors. The first factor is consumers' individual characteristics which determine the degree to which they recognize, understand and account for the labels in their purchasing decisions.

The second factor is informational and it directly affects the saliency of the label. On the one hand, the actual design of the label, the information it may contain, for example with regard to the lifetime energy costs, may not only raise consumers' attention, but could also contribute to overcoming behavioral biases such as hyperbolic discounting or bounded rationality. On the other hand, for any given label design, the level of enforceability of the regulation directly impacts its saliency. First, consumer decisions on purchasing energy-using durables are influenced by their demographic characteristics such as age, gender, education, geographic area, income, but also by psychological factors such as cognitive constraints, biases, bounded rationality, perception, inattention etc. Indeed, emerging evidence, which is still in its infancy, shows that there might be a significant gender bias in the purchase of energy- efficient appliances and the overall energy consumption of a household (Wang et al. 2021). A number of behavioral constraints and biases have also been deemed responsible for the energy-efficiency gap. For example, the limited attention and perception biases lead consumers to give less weight to less salient but important product attributes, such as the lifetime running cost of an energy-using durable (Schubert and Stadelmann 2015; Cattaneo 2019). Other explanations involve consumers' inaction towards energy-efficient purchases due to the status-quo bias or the sunk- cost fallacy (Gillingham et al. 2009; Blasch and Daminato 2018).

Second, beyond their individual characteristics, the optimality of consumers' decisions is influenced by informational factors such as the actual design of the regulation and its enforcement. For instance, Heinzle and Wüstenhagen (2012) find that consumers are sensitive to the framing of the energy classes, i.e. the A-plus scale versus the A-G scale, with the former reducing the importance of energy-efficiency in consumers' purchase decision. Moreover, the level to which the retailers of energy-consuming durables comply with the Labeling Regulation and the quality of their sales personnel determine the saliency of the labels and how well the consumer is informed.

Research that aims at understanding how consumers respond to energy labels and what strategies can increase consumers' awareness of the energy-efficiency product attribute has mainly investigated the behavior of US consumers and, consequently, assessed the US policies (Anderson and Claxton 1982; Allcott and Sweeney 2017; Houde 2018). Similar studies considering the EU markets and the EU regulations are surprisingly rare and they largely focus on the behavior of the Western EU consumers (Sammer and Wüstenhagen 2006; Heinzle and Wüstenhagen 2012; see also the literature surveyed in Schleich, Durand and Brugger (2021)).

There are a few recent studies which explore zhe effectiveness of labels in appliance choice. Andor et.al. (2020) using a survey of German consumers explore the impact of the design of labels. They present evidence of consumers opting for more energy efficient appliances when presented with annual operating cost information. They also report that many consumers place a value on energy efficiency beyond its economic implications.

Schleich et. al. (2021) explore the times series of evolution of the shares of different energy classes of refigerators in various european countries following the introduction of the previous labeling framework in 2011. They do find that the introduction of labels have contributed in the increase in the average efficiency of appliances in the market, but also caution that some of this change would have happened in the absence of the labeling policies as well and as a result invite caution in attributing the developments to the success of the policies.

To the best of our knowledge, there is no study evaluating of the implications of the new labeling framework introduced in March 2021 in the European Union. Our paper is a first step in understanding and documenting the observed effects of the new labels. This in itself is worthwhile in our opinion, however, our results should also prove to be a useful input to more structural models of this market which then can be used for further counterfactual analysis.

To be expanded...

4 Data

We use a panel dataset from GfK for the market of refrigerators in Germany with montly observations between January 2019 and December 2022. The product-level data consists of sales, prices, and various product characteristics, broken down by two distribution channels: the traditional or "brick-and-mortar" channel and the online channel.[1] GfK collected this information from a comprehensive sample of retailers, covering almost all the sales in Germany. A limitation of the available data is that it is aggregated across retailers within each country and as a result we cannot account for different strategical choices of retailers in our analysis.[2]

[1] GfK uses a "point of sales tracking" technology, which reports which products are sold, when, where, and for how much, both at online and offline outlets on a monthly (or sometimes weekly) basis. The data was collected directly from the electronic point of sales systems from retailers and resellers. Sales were tracked at the individual stock-keeping unit level and coded with a full set of features using a cohesive international methodology to allow for accurate comparison both within and across European markets. Any brand or model that was found to be sold in the covered countries is tracked, unless the brand is exclusive, in which case it is still audited but with a label that hides its exact origin. Sales volumes and turnover per item were gathered at the same time as the model specification information. The price of the item was calculated as turnover divided by units sold.

[2] The underlying data cover the following types of retailers: system houses, office equipment retailers, computer shops, consumer electronics stores, mass merchandisers, pure internet players, mail orders/online catalogs. It does not include duty-free shops, gas stations, door-to-door, street markets, discounter stores,

Each refrigerator or "product" is described by two identifiers: (i) the brand, such as Samsung or Bosch; (ii) the model, such as RB31FERNDSA in the case of Samsung. An observation in our panel dataset is thus a product (brand and model), distribution channel (traditional or online), and period (month). For the purposes of the present study, we will aggregate the sales in the online and offline channels and focus on total sales in Germany in the four years where our data provides information. This aggregation results in 160188 model-month observations. For each observation, we have the quantity sold and corresponding revenues generated. Price variable for a model in month is then computed as the ratio of the revenues to the quantities sold. For each model we have an extensive set of characteristics, and a subset of these characteristics will be used in our analysis below.

4.1 Descriptive analysis of the data

Our dataset covers almost the universe of models sold in Germany between 2019 and 2022. In Table 1, we present a summary of the supply of refrigerators and their sales over the years in Germany. It is interesting to note that the number of available models peak in 2021, the year where the new labeling framework is introduced. This is not a coincidence, however. Producers of refrigerators in Europe has used the new regulation to overhaul their product portfolios. As a result many models have been removed from the market following the introduction of the new labeling framework, while many new models have been introduced to replace them with the new labeling conventions. Nevertheless, this increase in models did not necessarily result in an increase in consumption. In fact, it looks as if the sales were somewhat higher during the first lock-downs due to the pandemic; the sales in both 2020 and 2021 are slightly higher than the other two years in the database.

Table 1: Number of models and sales by year

Year	# Models	Sales
2019	4859	2814548
2020	5529	3122098
2021	6431	2952096
2022	5586	2821378

The refrigerators in the data-set are distributed to several main types by GfK. The breakdown of the sales figures for this group of refrigerators are presented in table 2. In this table,

and direct sales (to staff, hotels, schools, hospitals, etc.). The sample is representative both for the smaller independent sellers as well as for the large chain stores.

we calculated montly total sales of each type and then averaged this figure over the four years. The resulting average-monthly-total-sales figure is presented in the second column of table 2. We present the number of models on offer averaged over months in the third column. In the data, by far the most important product category is the 2 door refrigerators with a freezer on the bottom. It looks as if this type is the most appealing design for households. The next popular group of refrigerators seems to be 1 door refrigerators that are larger than 80 cm in height. In the following we will focus on these three groups of refrigerators which fit this criteria.

Table 2: Average of monthly total sales with respect main refrigerator type

Main Types	# Models	Sales
1 DOOR 81 - 90 CM	622	56006
1 DOOR >90 CM	719	40206
1 DOOR UP TO 80 CM	48	4583
2 DR FRZ. BTM	1368	108544
2 DR FRZ. TOP	228	13154
3+ DOORS	112	4501
SIDE BY SIDE	241	16966

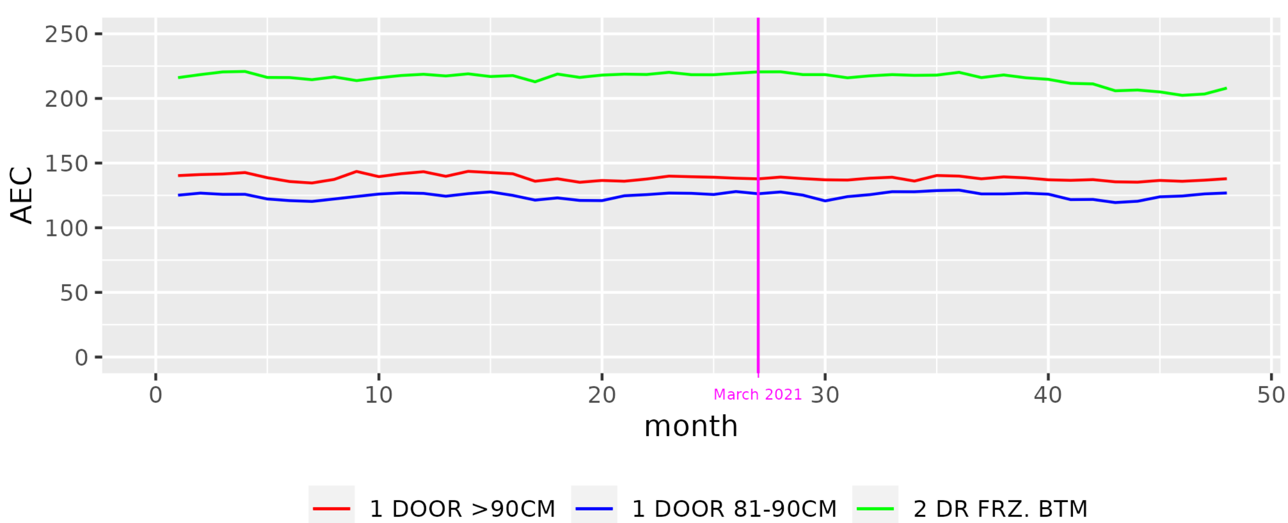
Especially arround the introduction of the new labeling policies, the producers have overhauled their product portfolios. In some case, sales of refrigerators which are removed from the market by their producers linger on as some units remain in the inventories of retailers. We decided to drop refrigerators that does not appear in the data set with more than five units sold for at least six months. For all these refrigerators, we eliminate the observations where their sales do not exceed 5 units in a month as well. This allows us to eliminate the refrigerator sales which took place to clear inventories.

When we take this reduced sample, and further focus on those refrigerators with two doors and bottom freezer as well as refrigerators with one door that are taller than 80cm, the remaining sales in our data account for roughl 82.5% of total sales in the data set. We also break the one door refrigerators into two groups with one group containing refrigerators with height between 81 to 90 cms, and the other group containing the refrigerators taller than 90cm. We believe the remaining data should be quite informative in terms of the dynamics of energy efficiency charactersitics of the refrigerators sold in Germany.

In our analysis, we will include those characteristics which we deem essential for the operation of a refrigerator. An important group of characteristics provide information on the energy usage of the refrigerator in question. As mentioned in section 2, the definition of annual energy consumption, standarized annual energy consumption and consequently labeling scheme has changed with the new framework. In order to explore time series evolution of average annual energy consumption figures, we constructed a unified annual energy consumption variable as follows. In those cases where the only annual energy consumption with the prior framework is known, we took this value to correspond to the annual energy consumption of the refrigerator. Similarly, for brand new models, we only have access to annual energy consumption figure with the new regulation after March 2021 and hence use this for these refrigerators. When we have both the new and old annual energy consumption figure, we took the arithmethic average of these two figures and use it as our unified annual energy consumption measure.

We think that it would be intersting to track the evolution of average annual energy consumption of different types of refrigerators sold in the market. To this end, we have constructed sales weighted average annual energy consumption figures for the three types of refrigerators we focus on which we present in figure 2. Although the figure shows that the annual energy consumption to increase with refrigerator size, the change in the labeling framework did not seem to cause a change for all three types of refrigerators. This is the first indication we find in the data that the policy change implemented in March 2021 may not have a noticable impact on the nature of refrigerators purchased by consumers in the market.

Figure 2: Monthly sales weighted average annual energy consumption for different refrigerator types



Given that figure 2 shows only the annual energy consumption of an average refrigerator, it would be reasonable to ask whether consumers changed the size of the refrigerators they buy while keeping the annual energy consumption similar to before. In order to investigate this, we plot in figures 3 and 4, the sales weighted volume of a refrigerator and annual energy consumption per liter for the three different types of the refrigerators.

Figure 3: Monthly sales weighted average volume for different refrigerator types

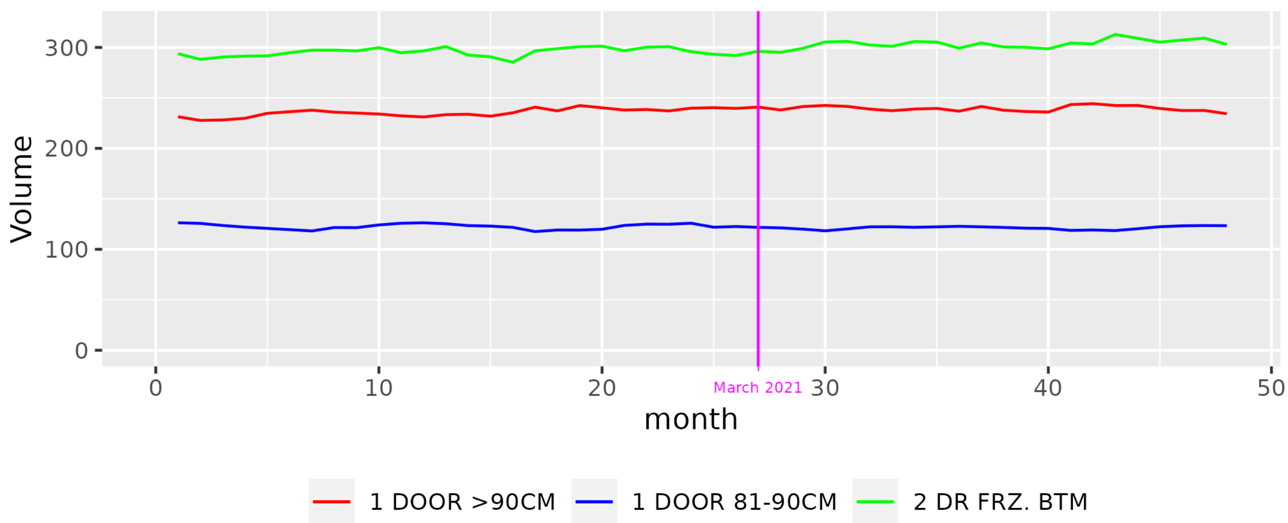
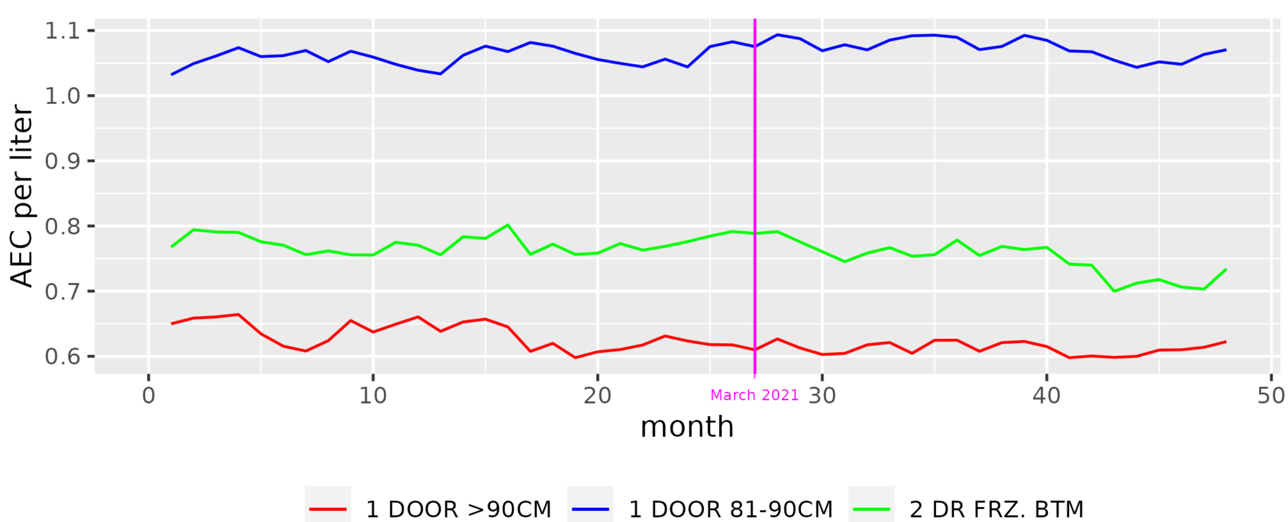


Figure 4: Monthly sales weighted average annual energy consumption per liter for different refrigerator types

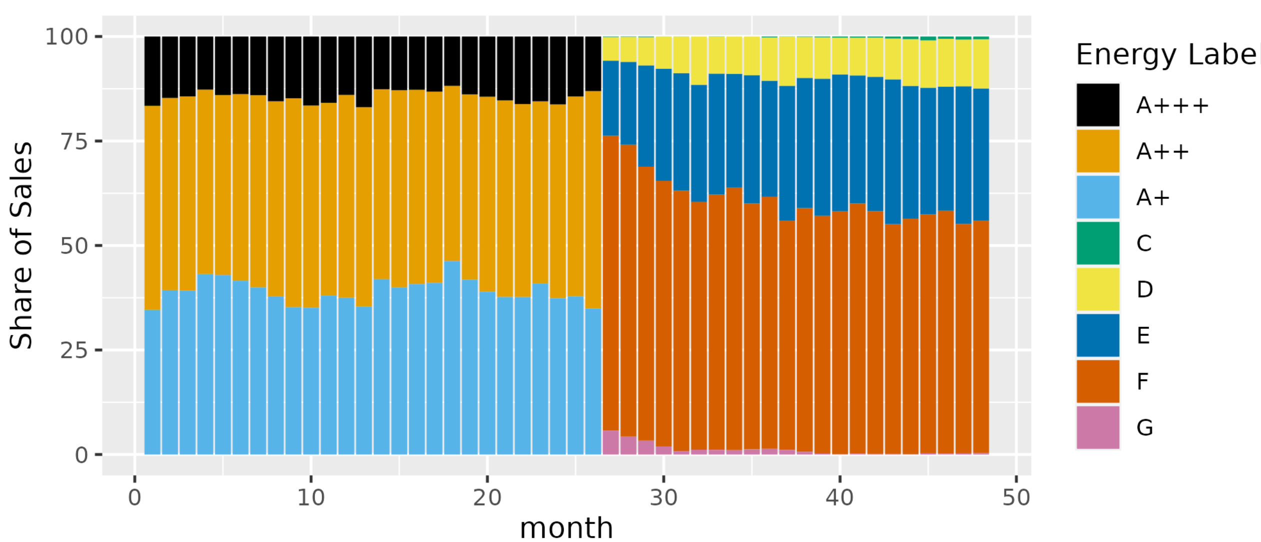


As indicated in figure 3, an interesting pattern emerges: one door refrigerators with a height larger than 90cm happens to be also large in volume, although they consume relatively low energy. Indeed because of this property, these refrigerators are the ones with lowest per liter annual energy consumption, while the least efficent ones are the refrigerators which have a height between 81 and 90cms. It is important to note that a considerable number of refrigerators with one door do not have a freezer. This in turn justifies the lower annual energy consumption of these refrigerators.

Regardless, it is not possible to recognize a trend in one direction or another after the introduction of new labels. It seems that the German consumers continued to purchase similar types of refrigerators with similar values of annual energy consumption and volume after the new labeling framework was introduced in March 2021.

In a next step, we condider how the three refrigerator types we consider have been allocated between the energy labels before and after the labeling framework change in March 2021. For each type of refrigerator, we constructed a time series of shares of labels before the policy change (A+++,A++,A+), and after the policy change (C,D,E,F,G). Although there are a few refrigerators with labels A and B appearing in the dataset towards the end of our coverage, these do not yield a large share, and hence we ignored them in constructing the following transition figures. Similarly, we have ignored the small number of observations with energy labels below the A+ level prior to the implementation of the new labeling framework. The resulting transition figures for the three refrigerator groups are presented in figures 5, 6 and 7, respectively.

Figure 5: Evolution of energy labels for 1 door refrigerators with height between 81-90cm



The energy label transition figures suggest that the one door refrigerators do have very few models which obtain the energy label C after the implementation of the change in

Figure 6: Evolution of energy labels for 1 door refrigerators with height larger than 90cm

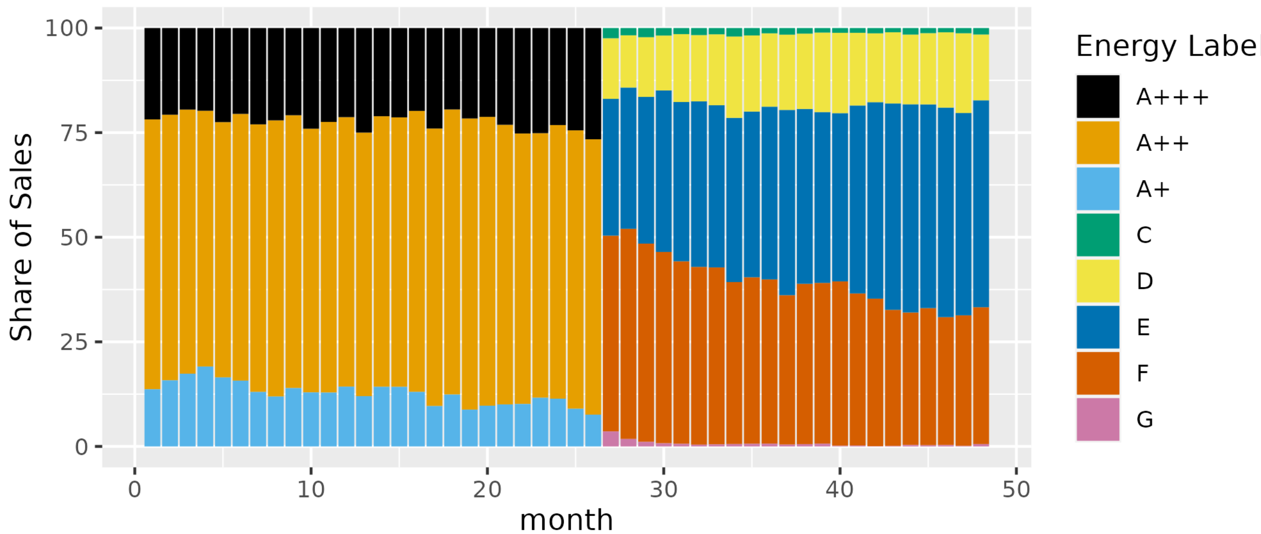
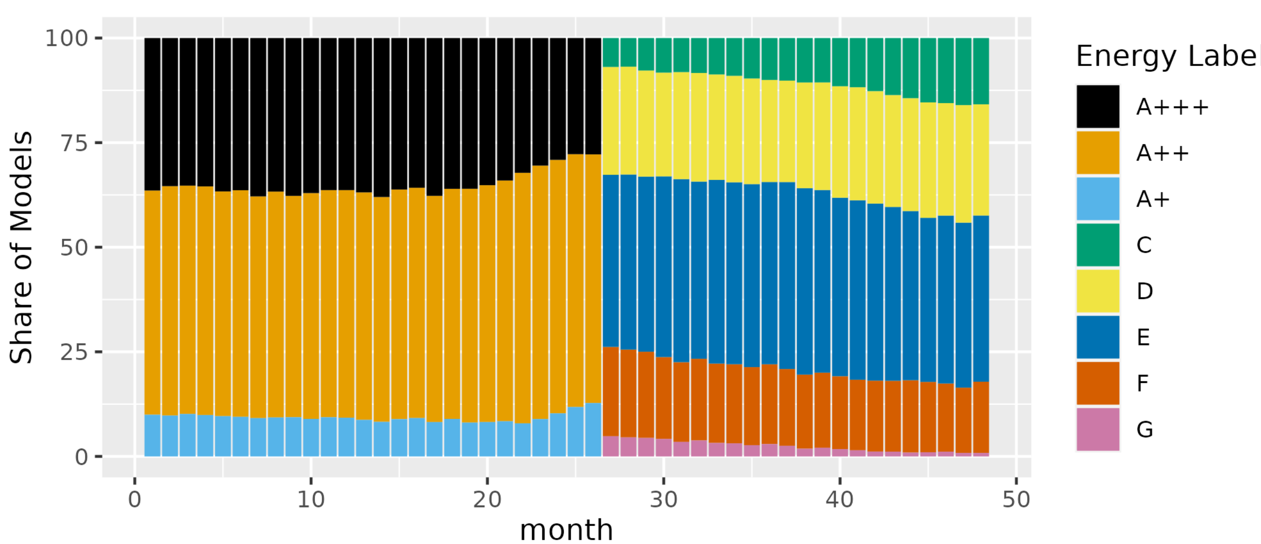


Figure 7: Evolution of energy labels for 2 door refrigerators with freezer on the bottom height



the labeling framework. Both types of one door refrigerators mainly have relatively stable distribution of labels prior to the change, and following the change in the labeling framework, the most noticable developments suggest that the sale of refrigerators with an energy label F has declined, while the sales of refrigerators with an energy label of E has increased.

The sales figures for the two door refrigerators with a freezer on the bottom suggest more encouraging developments. It seems to be the case that the sale of refrigerators with an energy label of A++ has been increasing prior to the implementation of the new labels, but subsequently, the sales of refrigerators with a label of C—the highest level at the time of the implementation of the new framework, has started to increase. It seems this increase came at the expense of the lowest levels of the labels with F and G.

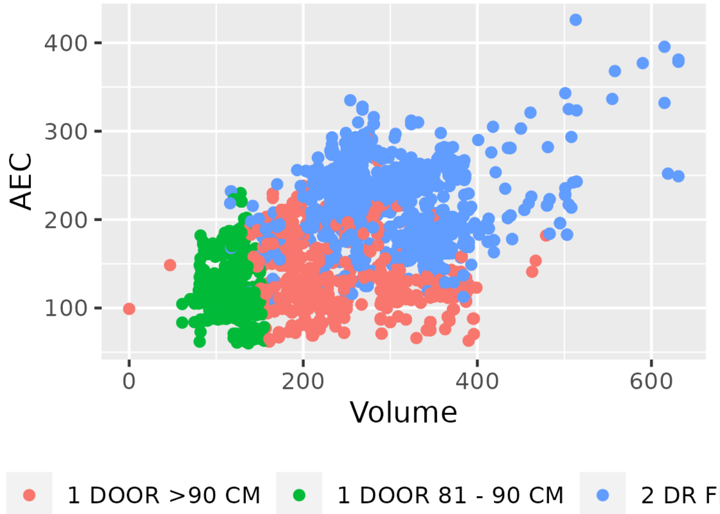
As can be expected, the energy consumption of a refrigerator increases with its volume. To verify this relationship we have constructed a scatter plot of refrigerators where the x-coordinate corresponds to the volume, and y-coordinate corresponds to the annual energy consumption. This graph is presented in figure 8. There seems to be a clear positive relationship between the volume of a refrigerator and its annual energy consumption as expected. Morever, we assigned different colors to the three different types of refrigerators that we are focusing on. It turns out that the three groups of refrigerators are perfectly clustered where the two door refrigerators tend to be largest in volume and consequently use more energy. One door refrigerators are also clearly separated along the volume dimension. It is interesting to note that this group can further be divided into two groups where the refrigerators without freezers have annual energy consumption levels below 150kwh for refrigerators with height exceeding 90cm and below 100 kwh for those with height between 81cm and 90cm.

To be expanded...

5 Determinants of refrigerator prices

In this section, we aim to understand how prices of the three types of refrigerators that we have been focusing are formed. In order to focus on samples with relevant variation, we have further restricted our attention to refrigerators with 4 freezer stars in the case of 2 door models, and additionally on refrigerators without freezer for the 1 door refrigerator models. It is remarkable that about 55% of the 1 door refrigerators come without a freezer. It turns out that seperate temperature control for 2 door refrigerators is quite important, while barely any 1 door refrigerator has this function available. In all the regressions we include month and brand fixed effects. These estimates are not explicitly reported in the

Figure 8: Volume vs Annual Energy Consumption Relationship



tables below, however they seem to have reasonable signs and sizes.[3]

An important characteristic of a refrigerator has to do with its construction type. A refrigerator can be freestanding, or can be integrated in or under a cupboard. We include in the regressions a variable which accounts for the construction of the refrigerators. There are mainly two types of contructions: built in/under and freestanding. The refrigerators from the three types we consider are distributed equally between these two construction types. It is initially difficult to construct a hypothesis regarding the price effect of the construction type.

Furthermore, for all types of refrigerators in consideration, we will include the following characteristics as we believe that they contribute to better functioning of a refrigerator: i) noise level measured in decibels, ii) ventilated air, and iii) led lighting. In all specifications, we regress the logarithm of the prices on the characteristics.

The noise generated by a refrigerator likely will disturb consumers, reducing their willingness to pay. As a result, we expect prices to decline with the decibel level of the noise generated by a refrigerator. Another characteristic we consider is the ventilated air functionality. Refrigerators with this functionality can keep cool by circulating the air inside and as a result is typically more efficient. Furthermore, this functionality helps eliminating odors insider the refrigerator. As a result, we expect the refrigerators with ventilated air functionality to have higher prices. Inside lighting of the refrigerator can contribute to its

[3]The month fixed effects allow us to ignore correcting for the inflation that has accelerated in Germany with 2021.

efficiency. In our sample about 47% of the refrigerators have led lighting and this feature is included in all of our regressions. ´

More importantly, we include the refrigerator volume in all of our analysis. As we already demonstrated in figure 8, there is a clear relationship between volume and annual energy use of a refrigerator. In exploring the effect of these variables on the price of a refrigerator, we will include the annual energy consumption of a refrigerator as well. Finally, we will include energy label for a rerigerator in our analysis of refrigerator prices. Clearly, the label is constructed as a function of annual energy consumption and volume of a refrigerator. Including these three variables should allow us to account for incremental effects of each of these variables on the formation of the prices.

We explore the pricing determinants of the three types of refrigerators separately. This allows us to see differential effects of product characteristics for different types of refrigerators. We also run two separate regressions for for the time period before and after the introduction of the new labeling policy. There is an inherent difficulty in comparing the role labels play in the both periods. Nevertheless, by running separate regressions we will at least be able to see the incremental contributions before and after.

The determinants of the prices for one door refrigerators with height between 81cm and 90cm can be found in table 3. The results based on observations prior to March 2021 are presented in the first column, while the results based on data following the introduction of the new labeling scheme are displayed in the second column. The results are mostly as expected. Interestingly the coefficients of characteristics in both regressions resemble one another quite a bit. It turns out that the freestanding refrigerators have lower prices compared to built in/under variants. Refrigerators without freezer are also cheaper. Price of refrigerators which have ventilated air functionality turns out to be significantly higher, although this effect is estimated to be smaller in the period following the introduction of the new labeling framework. Led lighting seems to positively contribute to the prices but more so prior to the new labels. The effect of the noise level of a refrigerator does not have significant effect prior to the new labels, while the regression coefficient in the second column is negative and significant. It is difficult to explain this point estimate, but given its very small size, we do not think it that noise level has an economically significant effect on prices.

A quite interesting observation is that the volume and annual energy consumption effect on the prices remain similar before and after the introduction of the new labeling policy. The estimates indicate that a larger refrigerator will be sold at a higher price. On the other hand, a refrigerator which uses more energy annualy will be cheaper. The energy labels prior to the labeling change have the expected effects. With the old labels, relative to "A+" refrigerators, the ones with the label "A+++" are most expensive, and those with the label "A++" are more expensive than the reference group. The effects of the labels following the introduction of the new labels seem to be also as expected as well. The reference group is "C"–the highest level of the energy efficiency class. Compared to this group refrigerators with the new label "D", "E", "F" and "G" are cheaper in that order.

The estimates for the second group of refrigerators, those with one door and height exceeding 90cm, are presented in table 4. The freestanding refrigerators seem to be cheaper for this class as well, while those with ventilated air functionality are more expensive. The larger refrigerators seem to have larger prices and the marginal effect of the volume seem to be similar across the time periods. Some of the point estimates, however, have unexpected signs and require further investigation. Effects of noise level and led lighting seem to be not robust in the two different periods that we consider. More puzzlingly, the refrigerators without freezers turn out to be more expensive. Moreover, quite unintuitively the refrigerators which use higher energy happens to be more expensive as well. One possible explanation for these findings could be that this group of refrigerators contains models which are sold for special use cases, such as beverage storage. Given the special purposes, the willingness to pay of consumers can be high, which in turn can result in higher retail prices as well. The effects of the energy efficiency labels before and after the introduction of the new labeling framework seems to be as expected. The refrigerators with labels indicating higher efficiency have higher prices.

The final set of estimates we will discuss are derived based on the data from refrigerators with two doors and freezer at the bottom. This is by far the most popular class of refrigerators sold in the market. Similar to the other two classes, freestanding refrigerators in this class tend to be also cheaper. Consistent with the other two types of refrigerators, ventilated air functionality seem to result in higher prices for this type as well. Different from the other two classes, for this type of refrigerators separate temperature control functionality plays a significant and positive role on the retail prices. This effect seems to be robust for the before and after periods. As with the larger one door refrigerators, noise level and led lighting seems to have conflicting effects in the two different periods. Once again the volume of a refrigerator contributes positively to the price. The estimates on the energy efficiency classes have the expected effects, and the more efficient a refrigerator, the more expensive it is. However, annual energy consumption for this type of refrigerators seem to also have a positive and significant effect on the prices. This is once again an unexpected finding

Table 3: Determinants of prices of 1 door refrigerators with height between 81-90cm

	Dependent variable:	
	log(price)	
	(1)	(2)
Freestanding	−0.299***	−0.306***
	(0.005)	(0.008)
Without Freezer	−0.142***	−0.226***
	(0.012)	(0.019)
Old AEC	−0.002***	
	(0.0002)	
New AEC		−0.002***
		(0.0003)
Volume	0.004***	0.004***
	(0.0001)	(0.0002)
Ventilated Air	0.504***	0.386***
	(0.022)	(0.025)
Noise	0.001	−0.012***
	(0.001)	(0.002)
Led Lighting	0.088***	0.028***
	(0.005)	(0.007)
Label (A++)	0.084***	
	(0.008)	
Label (A+++)	0.192***	
	(0.016)	
Label (D)		−0.627***
		(0.062)
Label (E)		−0.716***
		(0.061)
Label (F)		−0.710***
		(0.060)
Label (G)		−0.997***
		(0.063)
Constant	5.515***	6.981***
	(0.054)	(0.104)
Brand FE	Yes	Yes
Month FE	Yes	Yes
Observations	11,218	6,558
R^2	0.860	0.810
Adjusted R^2	0.859	0.808
Residual Std. Error	0.167 (df = 11137)	0.203 (df = 6484)
F Statistic	853.011*** (df = 80; 11137)	378.092*** (df = 73; 6484)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 4: Determinants of prices of 1 door refrigerators with height larger than 90cm

	Dependent variable:	
	log(price)	
	(1)	(2)
Freestanding	−0.239***	−0.260***
	(0.009)	(0.011)
Without Freezer	0.418***	0.281***
	(0.014)	(0.013)
Old AEC	0.007***	
	(0.0002)	
New AEC		0.008***
		(0.0002)
Volume	0.002***	0.002***
	(0.0001)	(0.0001)
Ventilated Air	0.142***	0.098***
	(0.007)	(0.008)
Noise	0.008***	−0.038***
	(0.002)	(0.002)
Led Lighting	0.121***	−0.011
	(0.006)	(0.008)
Label (A++)	0.388***	
	(0.009)	
Label (A+++)	0.953***	
	(0.016)	
Label (C)		−0.114***
		(0.040)
Label (D)		−0.424***
		(0.038)
Label (E)		−0.772***
		(0.038)
Label (F)		−1.127***
		(0.040)
Label (G)		−1.635***
		(0.047)
Constant	4.238***	7.130***
	(0.059)	(0.070)
Brand FE	Yes	Yes
Month FE	Yes	Yes
Observations	12,944	8,228
R^2	0.815	0.813
Adjusted R^2	0.814	0.812
Residual Std. Error	0.218 (df = 12867)	0.226 (df = 8158)
F Statistic	744.220*** (df = 76; 12867)	515.383*** (df = 69; 8158)
Note:		*p<0.1; **p<0.05; ***p<0.01

and requires further investigation. One possibility is that simultaneously including the three variables, volume, annual energy consumption and energy label—which is determined by volume and annual energy consumption, is the reason behind the these unintuitive findings. In order to understand overall effect of efficiency on prices, one should probably construct a compostite effect of these three regression coefficients.

To be expanded...

6 Conclusions

In this paper, we endevaoured a first exploration of the effect of energy labels on the prices of refrigerators. The energy labels in the European Union have changed in March 2021 based on a new regulation decided in 2017. This change was intended to induce a move towards to consumption of more energy efficient products. We have data for refrigerators in Germany for the years between 2019 and 2022, and hence the policy change occured right in the middle of our data. As a result, we explored the implications of the new labeling framework from a number of angles.

We first decided to document simple measures of energy efficiency of purchased products. We first established that three types of refrigerators account for about 83% of the sales: 1 door with height 81-90cm, 1 dooor with height larger than 90cm, and 2 door with freezer at the bottom. We then explored the time series evolution of annual energy consumption for these three types of refrigerators. Although the analysis imply higher energy usage by larger refrigerators, it turns out the labeling change has had no visible impact on the average annual energy consumption of these refrigerator types within their own type. We then looked at the time series of the volume of the purchased refrigerators, as well as the annual energy consumption per liter of the same products. Our findings indicate that there is no visible effect of the new labeling policy on these dimensions either. Thus, at a first glance, the new labeling framework did not yield a change in the consumption patterns for refrigerators in Germany.

We then explored energy efficiency classes of purchased refrigerators. In terms of energy efficiency classes, there is some mild good news. The least efficient refrigerators—energy efficiency classes "F" and "G"—seem to have lost market share, while the more efficient refrigerators—energy efficiency classes "C" and "D"—have gained a larger share of the sales. It is however important to note that this change did not result in a decline in the average annual energy consumption of a refrigerator. It is important to further investigate this

Table 5: Determinants of prices of two door refrigerators with freezer at the bottom and 4 freezer stars

	Dependent variable:	
	log(price)	
	(1)	(2)
Freestanding	-0.532^{***}	-0.598^{***}
	(0.006)	(0.008)
Old AEC	0.001^{***}	
	(0.0001)	
New AEC		0.003^{***}
		(0.0002)
Volume	0.001^{***}	0.001^{***}
	(0.0001)	(0.0001)
Ventilated Air	0.091^{***}	0.060^{***}
	(0.005)	(0.006)
Noise	0.002^{**}	-0.004^{***}
	(0.001)	(0.001)
sep_temp_contr	0.108^{***}	0.111^{***}
	(0.005)	(0.007)
Led Lighting	0.026^{***}	-0.023^{***}
	(0.004)	(0.007)
Label (A+)	0.236^{***}	
	(0.046)	
Label (A++)	0.503^{***}	
	(0.047)	
Label (A+++)	0.801^{***}	
	(0.050)	
Label (D)		-0.152^{***}
		(0.011)
Label (E)		-0.512^{***}
		(0.018)
Label (F)		-0.771^{***}
		(0.027)
Label (G)		-1.166^{***}
		(0.038)
Constant	5.559^{***}	6.570^{***}
	(0.064)	(0.055)
Brand FE	Yes	Yes
Month FE	Yes	Yes
Observations	22,004	12,112
R^2	0.792	0.790
Adjusted R^2	0.792	0.789
Residual Std. Error	0.214 (df = 21917)	0.219 (df = 12032)
F Statistic	973.022^{***} (df = 86; 21917)	573.142^{***} (df = 79; 12032)
Note:		*p<0.1; **p<0.05; ***p<0.01

dynamic. As it stands, the new labeling framework has not resulted in a improvement beyond a cosmetic one.

We then explored the determinants of the refrigerator prices using reduced form regressions. Our goal in this type of analyis was to establish statistical regularities in the formation of prices which then can be used as an input more structural models which can be used for counterfactual analysis. This type of approach is next on our research agenda.

Let us briefly summarize our findings here. Refrigerators which are built in/under seem to be more expensive. Ventilated air functionality as well as seprate temperature control seem to also consistently positively contribute to refrigerator prices. We have mixed results regarding the effects of noise level of a refrigerator and led lighting which require further investigation. As it would be expected, we find that a refrigerator that is larger in size—has higher volume, will be sold at a higher price. This effect is quite robust across refrigerator types as well as the before and after analysis with respect to the introduction of the new labeling framework. We find that energy labels that indicate higher efficiency yield higher prices both before and after the new labeling framework came into effect as well.

We have encountered a number of puzzling results, however. While small refrigerators without freezer seems to be cheaper, larger one door refrigerators without a freezer seem to be more expensive. We suspect that this could be due to specialty use of large one door refrigerators and this result requires further analysis.

By far the most puzzling result is the positive and significant coefficient estimated on the annual energy consumption for large one door refrigerators as well as the two door refrigerators with freezer on the bottom. We think that this maybe an artifact of us including volume, annual energy consumption, and the energy label in the same regression. We intend to modify our modeling strategy to construct a reliable index these three interdependent variables to describe the efficiency properties of a refrigerator better. ´

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