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**Title: Evaluation on the efficiency of Chinese energy-saving household appliance subsidy policy: An economic benefit perspective**

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1                   **Evaluation of the efficiency of Chinese energy-saving household appliance**  
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3                   **subsidy policy: An economic benefit perspective**  
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9           **Abstract:**

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11           China has made great efforts to control energy consumption and reduce environmental  
12           pressure in recent decades. In the residential sector, the dramatic increase in the  
13           ownership of household appliances has driven the growth of electricity consumption,  
14           which calls for effective energy-saving policies. In this study, we exemplified the  
15           sales of refrigerators in Beijing, aiming to evaluate the effectiveness of current  
16           subsidy policies for stimulating the purchase of energy-efficient household appliances.  
17           In specific, we first selected ten pairs of refrigerators from six brands having similar  
18           functions, however different in their energy efficiency grades (EEG). By applying a  
19           combination of net present value (NPV) difference method and Conversion Method of  
20           Electrical Engineering Coefficient, we calculated and compared the changes in the  
21           NPV difference and dynamic investment payback period (DIPP) to evaluate the  
22           effectiveness of the policy. The results revealed that economic benefits were mainly  
23           generated in EEG2; thereby we suggest that the government can cancel subsidies for  
24           EEG2 refrigerators, and increase the subsidy amount for EEG1 refrigerators at a  
25           potential rate of 24% in the future.  
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55           **Keywords:** energy saving subsidy; energy efficiency label; economic benefit;  
56           household appliance  
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## 1. Introduction

Global warming is a world-wide problem raising substantial social and governmental attention (Faheemullah et al., 2015; Ji et al., 2019). Governments tend to promote the energy-saving subsidy policies for reducing greenhouse gases and slowing down the global warming effect (Bian et al., 2013; Galarraga et al.,2011; Gillingham et al.,2009). Therefore, it is necessary to have an appropriate energy-saving policy (Linares and Labandeira, 2010; Xia et al., 2019; Xu et al., 2019), having potential to reduce global carbon dioxide (CO<sub>2</sub>) emissions by 10% to 15% (International Energy Agency, 2009). The Chinese government has been formulating energy-saving policies since the 1980s and has issued a series of regulation measures and incentive policies for energy conservation (Li et al., 2020; Yuan et al., 2009). In 2009, the Chinese government had pledged to cut carbon intensity by 40-45% by 2020 compared with the 2005 level (Hu,2009; Yuan et al.,2012). To achieve this, in 2011, the State Council issued the '*Comprehensive Work Plan for Energy Conservation and Emission Reduction during the 12th Five-Year Plan Period*' and specified the low-carbon index for measuring energy conservation and emission reductions. In the *13th Five-Year Plan*, it was indicated that by 2020, energy intensity should decrease by 15% compared with 2015 (Yu et al., 2018). According to the '*Implementation Plan for Further Optimizing Supply, Promoting Steady Growth of Consumption, and Facilitating the Formation of a Strong Domestic Market (2019)*', jointly issued by the National Development and Reform Commission (NDRC),

1 another nine ministries in China, the Chinese central government encourages regional  
2  
3 governments to implement specific subsidies for energy-saving household appliances  
4  
5 tailored to local conditions (Gov.cn, 2019). To address the central government's  
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7 policy, a nationwide subsidy policy on energy-efficient appliances was widely  
8  
9 implemented. In Beijing, for example, the regional governments have adopted a three-  
10  
11 year subsidy policy for energy-efficient appliances since February 2019. An effective  
12  
13 energy-efficient subsidy could stimulate consumers to purchase more energy-efficient  
14  
15 appliances by improving their economic benefits (Allcott et al., 2015; Ma et al., 2013).  
16  
17 For rational consumers, they will make decisions based on the tradeoff of upfront  
18  
19 price and the electricity expenditure after purchasing (Gerardenet al., 2017; Xie and  
20  
21 Zhao, 2018). Even though energy-efficient appliances can consume less electricity  
22  
23 than normal products, the purchasing price could be higher. In this regard, the  
24  
25 economic benefits of energy-efficient products are ambiguous. A subsidy can improve  
26  
27 the economic benefits to reduce the total payment of energy-efficient appliances by  
28  
29 decreasing upfront price. As such, to what extent a subsidy policy can effectively  
30  
31 influence consumers' economic benefits is arguable. To a large extent, an  
32  
33 appropriately designed and implemented policy can improve the energy-efficient  
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35 products' economic benefits , utilizing minimum cost input or vice versa. Therefore,  
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37 the following research question was addressed in this study: *What are the economic*  
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39 *benefits of purchasing energy-efficient products and to what extent the current*  
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41 *Chinese energy-efficient subsidy influence on the cost comparison of products with*  
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43 *different EEGs?*  
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1 This rest of the paper is organised as follows. The literature review is given in the  
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3 second section, and Chinese energy-efficiency labelling policy and the subsidy policy  
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5 for energy-efficient household appliances is reviewed in the third section. We then  
6  
7 present our methodology, including data collection and analysis methods, in the fourth  
8  
9 section. The results and relevant discussions are presented in the fifth section,  
10  
11 followed by our conclusion.  
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## 16 **2. Literature overview**

17  
18 A stream of existing studies have focused on the adoption of energy-efficient  
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20 products and related subsidy policies. Energy-efficient products prompt a potential  
21  
22 reduction in energy consumption and CO<sub>2</sub> emissions, however consumers appear to be  
23  
24 hesitated in acceptance for energy-efficient products due to low or perceived  
25  
26 economic benefit leading to an energy-efficiency gap (Gerardenet al., 2017) that  
27  
28 individuals make decisions about energy efficiency leads to a slower diffusion of  
29  
30 energy-efficient products than other alternative optimal decision consumers would  
31  
32 make (Gillingham and Palmer, 2014). Several studies that explore the reasons for the  
33  
34 energy-efficiency gap and classify the key barriers to the adoption of energy-efficient  
35  
36 products as market failures including environmental externalities, inefficient pricing  
37  
38 of energy and lacking of information (Cohen et al., 2017; Gillingham and Palmer,  
39  
40 2014; Kallbekken et al., 2013). To bridge the energy-efficiency gap, energy-saving  
41  
42 policies, such as information strategies, efficiency standards regulation, and economic  
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44 incentives, have been implemented in various countries (Gillingham and Palmer, 2014;  
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46 Tietenberg, 2009).  
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1 Information strategies refer to providing consumers with adequate information to  
2  
3 solve the problem of information asymmetry, which have been proven to be effective  
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5 in bridging the energy-efficiency gap (Jeong and Kim, 2015; Stadelmann and  
6  
7 Schubert, 2018; Zhou and Bukenya, 2016). The more clear and simplified information  
8  
9 is provided for energy-efficient products, the more likely these products will capture  
10  
11 consumers' intention (Ek and Söderholm, 2010; Shen and Saijo,2009). In contrast,  
12  
13 complicated energy-efficiency information will be likely to decrease purchase  
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15 intention among those consumers having low level of literacy (Abrahamse et al.,  
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17 2007).  
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25 Efficiency standard regulation demonstrate that the government sets efficiency  
26  
27 standards for energy-using products, and supervises the enterprises according to the  
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29 standards, aiming at promoting the energy efficiency of energy-using products (Tao  
30  
31 and Yu, 2011). Tao and Yu (2011) evaluated the effectiveness of the efficiency  
32  
33 standards regulation for household refrigerators and concluded that on one hand, the  
34  
35 implementation of efficiency standards regulation can reduce both electricity  
36  
37 consumption and carbon emissions with a large potential. On the other hand , the  
38  
39 consequences of applying the efficiency standards greatly increase manufacturing  
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41 cost and retail price. Parry et al. (2014) evaluated the efficiency standard regulation  
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43 program and indicated that the efficiency standard regulation program can effectively  
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45 deal with market failure including environmental externalities and information  
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47 asymmetry. However, for environmental externalities, the preferred approach is  
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49 emission pricing measures, and for information asymmetry, information programs can  
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1 play an important role. In either case, efficiency standards appear to be a second-best  
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3 measure due to the disadvantage of high policy cost.  
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5  
6 Energy-efficient subsidy policy is an effective economic incentive to reduce energy  
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8 consumption and to deal with market failures including environmental externalities,  
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10 information asymmetries and so on. (Allcott et al., 2015). The effectiveness of the  
11  
12 energy-efficient subsidy on energy conservation has been evaluated and proven to be  
13  
14 significant (Allcott et al., 2015; Wang et al., 2017). Furthermore, when the targets and  
15  
16 levels of subsidies are appropriate, the subsidy policy could be regarded as the most  
17  
18 cost-effective measure to save energy and reduce emissions (Allcott and Greenstone,  
19  
20 2017; Datta and Guliti, 2014; Filippini et al., 2014).  
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28 In addition, environmental awareness and social interaction have been investigated  
29  
30 as influential factors in the adoption of energy-efficient products (Jia et al., 2018; Li et  
31  
32 al., 2019; Nie et al., 2019). However, most scholars still believe that economic  
33  
34 benefit is the most important determinant in stimulating consumers to adopt energy-  
35  
36 efficient products (Gerarden et al., 2017). Feng et al. (2010) found that approximately  
37  
38 one-third of consumers only consider the price of energy-efficient products, rarely  
39  
40 taking the costs of electricity consumption into consideration. And more scholars  
41  
42 believed that both overall economic benefits and energy prices are both important  
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44 factors for consumers to consider when making purchase decisions (Fuerst and Singh,  
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46 2018; Mills and Schleich, 2010; Panzone, 2013).  
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55 The aforementioned studies revealed that even though various factors influence the  
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57 adoption of energy-efficient products, their economic benefits are fundamentally  
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1 important. Among various policies, the economic incentive policies played an  
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3 outstanding role in promoting the adoption of energy-efficient products especially  
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6 when the targets and levels of subsidies were appropriate.  
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9 In this study, we evaluated the efficiency of Chinese energy-efficient subsidy policy  
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11 by directly investigating the economic benefits of labelled household appliances with  
12  
13 different energy efficiency grade (EEG) levels in the absence and presence of  
14  
15 subsidies. Net present value (NPV) and dynamic investment payback period (DIPP)  
16  
17 were shown to be effectively measure the economic benefits of labelled appliances  
18  
19 (Enongene et al., 2017). NPV differences were used to measure the difference in  
20  
21 benefits between appliances with different EEG levels, as these benefits definitely  
22  
23 drive consumers' purchase decisions (Enongene et al., 2017; Gerarden et al, 2017).  
24  
25 We chose refrigerator as our research focus because refrigerators, compared with  
26  
27 other household appliances, consume more electricity (Tao and Yu, 2011). Moreover,  
28  
29 due to the fact that refrigerators must be charged an entire day without being turned  
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31 off, the EEG level can significantly influence on household electricity consumption.  
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33 We acknowledge that it can be difficult to collect a pair of refrigerators with identical  
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35 functions but different EEG levels. Thus, we selected refrigerators with similar  
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37 functions at different EEG levels from the same brands, and we proposed a novel  
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39 adjustment method to adjust refrigerator functions mathematically to the same level.  
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### 57 **3. Chinese energy-efficiency labelling and household appliance subsidy policy**

#### 58 *3.1 Energy-efficiency labelling policy*

1 The energy-efficiency label is one of the most important types of environmental  
2 labels, contributing to the reduction of energy consumption (Gillingham and Palmer,  
3 2014). As the original version of the energy-efficiency labelling policy, in early 1998,  
4 the 'Energy Conservation Law of the People's Republic of China' required companies  
5 to explicitly indicate the energy consumption level of their products on product labels  
6 and in manuals (Zhou et al.,2010). In 2004, to further develop energy-saving  
7 technologies and improve energy efficiency, the Chinese government designed and  
8 issued the 'Measures for the Administration of Energy Efficiency Labels', which was  
9 the first formal energy-efficiency labelling policy in China. In 2016, to further  
10 improve the efficiency of energy consumption and contribute to the development of  
11 energy-saving technologies, the Chinese government amended and implemented the  
12 'Measures for the Administration of Energy Efficiency Labels'. Based on the policy,  
13 energy-using products in China are categorised into five EEG levels, from EEG1 to  
14 EEG5, where EEG 1 represents the highest energy-efficiency level and EEG 5  
15 represents the lowest energy-efficiency level. Among these, EEG 3 represents the  
16 average energy-efficiency level in the market, while EEG 4 means that the energy-  
17 efficiency level is below the average. Products ranked at the EEG 5 level are restricted  
18 from market entrance under the policy.

### 3.2 *Subsidy policy for energy-efficient household appliances*

52 Even though energy efficiency labels provide information about the energy-  
53 efficiency levels of household appliances, higher prices of energy-efficient household  
54 appliances constrains consumers' purchase intentions. As such, energy-efficient  
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1 household appliance subsidy policies have been adopted by the government. In 2009,  
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3 the Chinese government implemented a household appliances trade-in policy aiming  
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5 at stimulating the demand for domestic household appliances, saving energy, reducing  
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7 emissions and eventually contributing to the development of a domestic circular  
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9 economic ecosystem. In 2012, the Chinese government implemented a one-year  
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11 energy-efficient household appliance subsidy policy to support the development of the  
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13 market of energy-efficient products and lead consumers towards green consumption.  
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19 In 2019, the NDRC, Ministry of Industry and Information Technology (MIIT),  
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21 Ministry of Commerce and another seven government agencies issued the  
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25 ‘Implementation Plan for Further Optimizing Supply, Promoting Steady Growth of  
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27 Consumption, and Facilitating the Formation of a Strong Domestic Market (2019)’.  
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31 This policy states that local governments will support the sales of green smart  
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33 household appliances. Appropriate subsidy policies can be adopted and applied to  
34  
35 stimulate the sale of these high-quality, high energy-efficiency household appliances.  
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39 Beijing is the pioneer in promoting energy-efficient products in China. In 2015,  
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41 Beijing began to implement a three-year subsidy policy to encourage the purchase of  
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43 energy-efficient products, which attracted substantial attentions from consumers.  
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47 Furthermore, a new three-year subsidy policy, implemented by the Beijing  
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49 government in 2019, also significantly generated the sale of energy-efficient products.  
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52 Under this policy, the sale of energy-efficient household appliances has experienced  
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54 high market growth. From 1 February to 6 March 2019, the total sales of energy-  
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56 efficient products were 338 million RMB, 20% higher than the previous year. Subsidy  
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1 policies will further encourage consumers to choose energy-efficient products. To  
2  
3 further stimulate the sale of energy-efficient products, the new three-year subsidy  
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5 policy implemented in Beijing will subsidise products like energy-efficient household  
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7 appliances, depending on their EEG levels, with a subsidy rate ranging from 8% to  
8  
9 13%. Specifically, EEG1 and EEG2 energy-efficient household appliances will  
10  
11 receive a subsidy rate of 13% and 8% respectively, with a highest subsidy amount set  
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13 at 800RMB per item.  
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20 In this context, this paper aims to evaluate the efficiency of the recent three-year  
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22 policy implemented in Beijing. Refrigerators were chosen as the research focus  
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24 because of their continuous operation and high-power consumption. As Chinese  
25  
26 refrigerators only have three EEG levels, namely EEG1, EEG2 and EEG3, according  
27  
28 to the policy, only EEG1 and EEG2 refrigerators will receive the subsidy (13% and  
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30 8%), while refrigerators at and below EEG3 levels will not receive the subsidy.  
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36 Therefore, this study will compare and examine the economic benefits and policy  
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38 efficiency between refrigerators at EEG1 and EEG2 levels.  
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#### 45 **4. Methodology**

##### 46 *4.1 Approach of NPV difference in the refrigerator lifecycle*

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51 As the fundamental elements of the decisions on purchasing household appliances,  
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53 total cost was used to measure the economic benefits of purchasing energy-efficient  
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55 products. And the minimising cost that consists of equipment purchase cost and  
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57 discounted operating cost indicates the optimal economic benefit (Gerarden et al.,  
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1 2017). To provide information about the economic benefits of refrigerators with  
2  
3 different EEG levels, the NPV difference approach (Horngren et al.,2013) was  
4  
5 adopted to measure the gap between a pair of refrigerators with different EEG levels.  
6  
7 In detail, we first calculated the NPV of each type of refrigerator, after which we  
8  
9 calculated the NPV difference between the two types. Specifically, NPV difference  
10  
11 measures the NPV of purchasing a refrigerator with a lower EEG level minus the  
12  
13 NPV of purchasing a refrigerator with a higher EEG level. If the NPV difference is  
14  
15 positive, the refrigerator with the higher EEG level can be said to generate more  
16  
17 economic benefits for consumers or vice versa. To better measure the economic  
18  
19 benefits of refrigerators at different EEG levels, the NPV and NPV difference  
20  
21 calculated in this paper were considered for refrigerators over their entire lifecycle. In  
22  
23 existing studies, the lifecycle of an appliance includes its purchase, use, maintenance  
24  
25 and recycling (Zhou and Zhen, 2018). Compared with appliances which need frequent  
26  
27 maintenance, refrigerators are regarded as durables, meaning they require much less  
28  
29 maintenance (Yu and Guo, 2016). In this regard, the present study considered the  
30  
31 stages of purchase, use and recycling in the lifecycle in line with previous studies  
32  
33 (Stadelmann and Schubert, 2018; Tao and Yu, 2011), and the cost generated in these  
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35 stages was considered as the refrigerators' economic benefits.  
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50 We evaluated a refrigerator's economic benefits by considering four different  
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52 scenarios for its service life: 4 years, 8 years, 12 years and 16 years. A positive  
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54 calculated NPV difference indicates a better economic benefit of a higher EEG-level  
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56 appliance. Meanwhile, the efficiency of the subsidy policy was measured by  
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1 comparing the NPV difference in the absence and presence of subsidies.  
2

3 To compare the NPV of appliances with different EEG levels, we adopted the  
4 following formulae to calculate the NPV difference (NPVD):  
5  
6

$$7 \quad NPVD = \sum_0^t \frac{C_t + M_t}{(1+r)^t} - C_0 + \Delta RI \quad (1)$$

8 where:  
9

$$10 \quad C_0 = P_{high} - P_{low}$$

$$11 \quad C_t = EC'_{low} - EC_{high}$$

$$12 \quad EC_{high} = E_{ahigh} * 0.55 * 365$$

$$13 \quad EC'_{low} = E'_{alow} * 0.55 * 365$$

14 where NPVD is net present value difference between higher EEG-level  
15 refrigerators and lower EEG-level refrigerators,  $C_t$  is the cost difference of electricity  
16 consumption between lower EEG-level refrigerators and higher EEG-level  
17 refrigerators in year  $t$ , which essentially reflects the cost saved by the higher EEG-  
18 level refrigerators compared with the lower EEG-level refrigerators.  $C_0$  is the cost  
19 difference in year 0, which is the price difference between higher EEG-level  
20 refrigerators and lower EEG-level refrigerators.  $M_t$  represents difference in  
21 maintenance costs between higher and lower EEG-level refrigerators. Since  
22 refrigerators require very little maintenance over their lifecycle –and even if they do,  
23 there was no significant difference in the maintenance costs of refrigerators with  
24 different EEG levels in each pair after adjustment in this study – we assumed  $M_t = 0$   
25 for  $t > 0$ .  $\Delta RI$  here stands for difference in refrigerator recycling between both  
26 refrigerators. When we calculated NPV differences between both refrigerators, we  
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1 considered the entire lifecycle of refrigerators from purchase to use to recycling, so  
2  
3 we needed to consider the value of a refrigerator after its service life, such as the  
4  
5 value obtained from recycling. However, it should be noted that after adjustment,  
6  
7 refrigerators were regarded as identical with the exception of their EEGs. Therefore,  
8  
9 the values generated in the process of recycling should be the same for both  
10  
11 refrigerators, which means the difference concerning the recycling value was zero.  
12  
13  $P_{high}$  is the price of refrigerators with a higher EEG level, while  $P'_{low}$  is the adjusted  
14  
15 price of refrigerators with a lower EEG level, a calculation which will be discussed in  
16  
17 detail in the following sub-section.  $EC_{high}$  are the annual costs of electricity  
18  
19 consumption of refrigerators with a higher EEG level, while  $EC'_{low}$  are the adjusted  
20  
21 annual costs of electricity consumption of refrigerators with a lower EEG level.  $E_{ahigh}$   
22  
23 and  $E'_{alow}$  is the daily electricity consumption for refrigerators with a higher EEG  
24  
25 level and the adjusted daily electricity consumption for refrigerators with a lower  
26  
27 EEG level, respectively, a calculation which will also be discussed in the following  
28  
29 sub-section. Notably, we assumed 365 days each year, and we set the price of  
30  
31 electricity at 0.55RMB/kWh (Chen and Zuo, 2018). Finally,  $r$  stands for discount rate.  
32  
33 To be consistent with the savings benchmark interest rate of the People's Bank of  
34  
35 China,  $r$  was 2.75%.

36  
37 In addition, consumers will also take the investment payback period into  
38  
39 consideration. The shorter the period is, the lower risk consumers will have. To  
40  
41 measure the period for an investment's payback, we adopted a widely used indicator:  
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43 dynamic investment payback period (DIPP). This indicator represents the period from  
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1 the beginning of the investment to the time at which the cumulative discounted cash  
2  
3 flow is equal to zero. This can be calculated using the following formula:  
4

$$P_t = (T_{NPVD \geq 0} - 1) + \frac{|N_{T-1}|}{N_T} \quad (2)$$

5  
6  
7  
8 where:

9  
10  
11  $P_t$ -----Dynamic investment payback period

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13  
14  $T_{NPVD \geq 0}$ -----The period from the present year to the year in which the NPVD initially  
15  
16 becomes positive.

17  
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19  
20  $N_T$ -----The NPVD in the period from the present year to the year in which the  
21  
22 NPVD initially becomes positive.

23  
24  
25  $|N_{T-1}|$  -----The absolute value of the NPVD in the period from the present year to  
26  
27 the year before the NPVD initially becomes positive.  
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#### 32 33 34 *4.2 An approach to adjusting refrigerators' price, volume and electricity consumption*

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36 As it can be difficult to find a pair of refrigerators which are identical in their  
37  
38 volume and function but different in their EEG levels, it would have been  
39  
40 inappropriate to directly calculate NPV difference based on the price and electricity  
41  
42 consumption of different refrigerators. As such, in this research, we managed to  
43  
44 eliminate all other influences from refrigerators' functions (e.g. refrigerator volume,  
45  
46 compartment numbers) and focused instead on measuring the economic benefits  
47  
48 conferred by refrigerators with different EEG levels. Towards this end, we adjusted  
49  
50 the price of refrigerators with a lower EEG level by multiplying an adjustment  
51  
52 coefficient that was equal to the ratio of adjusted volume of a refrigerator with a  
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1 higher EEG level and a lower EEG level. Specifically,  
2  
3

$$4 P'_{low}=P_{low} * V'_{high}/V'_{low} \quad (3)$$

5  
6 where:

7  
8  
9  $P'_{low}$ -----adjusted price for refrigerators with a lower EEG level

10  
11  $P_{low}$ ----- price for refrigerators with a lower EEG level

12  
13  $V'_{high}$ -----adjusted volume of refrigerators with a higher EEG level

14  
15  
16  $V'_{low}$ -----adjusted volume of refrigerators with a lower EEG level

17  
18  
19  
20 Here, the actual volume of refrigerators with both higher and lower EEG levels can  
21  
22 be standardised according to the formula below to ensure that a pair of refrigerators  
23  
24 are comparable (Yu et al., 2012).  
25  
26  
27  
28  
29  
30

$$31 V'=\sum_{c=1}^n V_c * F_C * W_C * CC * BI \quad (4)$$

32  
33 where:

34  
35  
36  $V'$ -----adjusted volume of refrigerators

37  
38  
39  $V_C$ -----Measured volume of a certain type of compartment

40  
41  
42  $F_C$ -----Compartment type factor; when it is a frost-free refrigerator with a  
43  
44 compartment with forced convection, the value is equal to 1.5; otherwise, it is equal to  
45  
46 1.0.  
47

48  
49  
50  $W_C$ -----The weighting coefficient of each type of compartment, detailed information  
51  
52 of which is included in Appendix A.

53  
54  
55  $CC$ -----Climate type correction factor<sup>1</sup>

56  
57  
58  $BI$ -----Refrigerator type indicator; when it is an embedded refrigerator, this value is  
59  
60

1 1.2; otherwise, it is 1.0.

2  
3 n-----The number of different types of compartments  
4  
5  
6  
7

8  
9 Moreover, as different volumes can lead to different degrees of electricity  
10 consumption, it was necessary to adjust electricity consumption when calculating the  
11 NPV difference for the costs of using both refrigerators. To do this, we referred to the  
12 Chinese GB12021.2-2015 programme, which is ‘The maximum allowable values of  
13 the energy consumption and energy efficiency grade for household refrigerators’  
14 (Gov.cn,2015), together with the adoption of the formulae used in the study by Yu et  
15 al. (2012) to adjust the refrigerator’s electricity consumption accordingly. The  
16 adjusted electricity consumption of the refrigerator with a lower EEG level was  
17 calculated as follows:  
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$$33 E'_{\text{alow}} = \eta_a * E'_{\text{base-1}} \quad (5)$$

34  
35  
36 where:

37  
38  $\eta_a$  -----The standard energy efficiency index, which is shown in Appendix B.

39  
40  $E'_{\text{base-1}}$ ----adjusted basic electricity consumption of lower EEG level refrigerators.  
41  
42  
43

44 Noting the adjustment of basic electricity consumption of less efficient refrigerators,  
45 it makes more sense to compare electricity consumption between less efficient and  
46 more efficient refrigerators at the same volume. In detail, the  $E'_{\text{base-1}}$  was obtained  
47 from formula (6) by replacing the volume data for less efficient refrigerators with the  
48 volume data for more efficient refrigerators when calculating basic electricity  
49 consumption for less efficient refrigerators. The  $\eta_a$  can be calculated from the  
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1 following formulae combined with formula (4) above. The detailed formulae are as  
2  
3 follows:

$$E_{base} = (M \cdot V' + N + CH + Dc) \cdot Sr / 365 \quad (6)$$

$$\eta_a = E_a / E_{base} \quad (7)$$

10  
11 where:

12  
13  $E_{base}$ -----basic electricity consumption for a refrigerator

14  
15  $M$ -----constant, here equal to 0.697 (KW.h/L)

16  
17  $N$ -----constant, here equal to 272 (KW.h)

18  
19  $CH$ -----The correction factor of temperature-varying compartment<sup>2</sup>

20  
21  $Dc$ -----The correction factor of door number; when the number of refrigerator doors  
22  
23  $\geq 4$ ,  $Dc$  is 50; for other types,  $Dc$  is 0

24  
25  $Sr$ -----Function correction factor<sup>3</sup>

26  
27  $E_a$ -----Actual electricity consumption labelled in the refrigerator

#### 28 29 30 31 32 33 34 35 36 37 38 39 *4.3 Data collection*

40  
41  
42 We selected six refrigerator brands – namely Haier, Midea, Ronshen, Meiling,  
43  
44 Hisense and Konka – as our samples for the following underlying reasons. First, the  
45  
46 ZhongYiKang database (2019) was used to provide authoritative data on China's  
47  
48 household appliance market. We collected the data from the leading refrigerator  
49  
50 brands with top-seven market share from 2015 to 2017 and the average prices in each  
51  
52 brand (Figure 1). To cross check the sampling strategy, we then collected the brands  
53  
54 with top-eight market share from the *All View Cloud* database (<http://www.avc->  
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1 mr.com/) in 2018 (Figure 2). Comparing the brands in both lists, Haier, Midea,  
2  
3 Ronshen and Meiling are listed in the top-five brands; whereas Hisense and Konka  
4  
5 are listed in the top-seven brands based on sales and sales volume, respectively. Thus,  
6  
7 we selected the six brands above as samples.  
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14 Fig. 1

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23  
24  
25 Fig. 2

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28  
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30  
31 Another factor to be considered in data collection is the price of products. When we  
32  
33 considered the current subsidy policy with the rate of 13% for EEG1 refrigerators, the  
34  
35 maximum subsidy amount for EEG1 refrigerators was 800 RMB. In other words, if  
36  
37 the price of refrigerators with EEG1 is higher than 6154 RMB (13% of which is 800  
38  
39 RMB), then regardless of the price of a product, consumers can only obtain an  
40  
41 800RMB subsidy. The average prices of the six selected refrigerator brands were far  
42  
43 less than 6154 RMB (Figure 1), which ensured the consistency of the subsidy rate of  
44  
45 each selected refrigerator brand. Even though international brands, such as Siemens,  
46  
47 Samsung and Panasonic, embrace their strong market position, according to the  
48  
49 ZhongYiKang database (2019), the average prices of Siemens, Samsung and  
50  
51 Panasonic were 6408 RMB, 7779 RMB and 8443 RMB, respectively, in 2017, which  
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1 were all significantly higher than 6154 RMB. Take Samsung as an example,  
2  
3 according to the energy-saving subsidy rate, the subsidy for EEG1 refrigerators  
4  
5 should be 1011 RMB (13% of average price), which is higher than 800 RMB; as such,  
6  
7 the subsidy amount would be 800 RMB, accounting for 10% of the average price. In  
8  
9 this case, the subsidy for EEG1 refrigerators has remained at 800 RMB. The subsidy  
10  
11 rates of refrigerators with different prices are different, which is not conducive to the  
12  
13 comparison and evaluation of the effect of energy-saving subsidies on refrigerators  
14  
15 with different EEGs. In this regard, the international brands (Siemens, Samsung and  
16  
17 Panasonic) with high prices were excluded from this study.  
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26 In this study, we obtained sales data from *Jingdong* (<https://www.jd.com/>) and  
27  
28 *Suning* (<https://www.suning.com/>), which are two of the most popular online  
29  
30 platforms for purchasing household appliances in China. **The reasons why we choose**  
31  
32 **these two online platforms are as follows. First, e-commerce platforms have become a**  
33  
34 **major channel for Chinese residents to purchase household appliances; Second, the**  
35  
36 **product prices of e-commerce platform is uniform, which can reduce the price**  
37  
38 **difference of products obtained from different channels.** Ten different pairs of  
39  
40 refrigerators with similar functions in each pair were collected. The information was  
41  
42 collected in March 2019, and included model, price, EEG level, volume, electricity  
43  
44 consumption, climate type, number of doors, embedded or not, frost-free or not, as  
45  
46 shown in detail in Table 1. To fit the purpose of this paper, we collected two groups of  
47  
48 data on refrigerators. Five pairs of refrigerators were included in Group 1, which was  
49  
50 used to compare the economic benefits between EEG 1 and EEG 2; the other five  
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1 pairs of refrigerators were included in Group 2, which was used to compare the  
2  
3 economic benefits between EEG 2 and EEG 3. The principle of matching refrigerators  
4  
5 was that each pair of refrigerators had basically the same function, but different EEG  
6  
7 levels, which facilitated the analysis of the impact of EEG levels on economic  
8  
9 benefits for consumers.  
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17 Table. 1  
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## 22 **5. Results and discussion**

### 23 *5.1 Economic benefit analysis*

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27  
28 Table 2 shows the NPV difference and DIPP of ten pairs of refrigerators with  
29  
30 different EEG levels, which was further categorised into two groups. Group 1  
31  
32 measured the NPV difference between EEG1 and EEG2 refrigerators and their DIPP,  
33  
34 whereas Group 2 measured the NPV difference between EEG2 and EEG3  
35  
36 refrigerators and their DIPP. The results in the absence and presence of subsidies  
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38 indicated the efficiency of the energy-efficient subsidy policy in China.  
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51 Table. 2  
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1 The results for DIPP for ten pairs of refrigerators showed how long it would take to  
2  
3 recoup the overpaid price for an energy-efficient refrigerator through saving  
4  
5 electricity cost. Observations in this study revealed a visible decrease in DIPP after  
6  
7 the implementation of the subsidy policy. Figure 3 illustrates the comparison of the  
8  
9 DIPP of pairs of refrigerators in the absence and presence of subsidies excluding pairs  
10  
11 of 1.1, 1.2 and 1.3, for which the DIPP was greater than 30 even in the presence of  
12  
13 subsidies. Both Figure 3 and Table 2 reveal that three pairs of refrigerators – namely  
14  
15 2.1, 2.2 and 2.5 – can obtain zero DIPP in the presence of subsidies. The results  
16  
17 indicate that after adopting the subsidy policy, the initial investment (purchase price)  
18  
19 of the refrigerators with a higher EEG level was not necessarily higher than that of the  
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21 refrigerators with a lower EEG level in these pairs.  
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31 When we examined four scenarios of service life (e.g. 4, 8, 12, 16 years), the  
32  
33 number of recoverable pairs in each scenario increased with the implementation of the  
34  
35 subsidy policy (shown in Figure 4). In more detail, with the implementation of the  
36  
37 subsidy policy, the recoverable pairs increased from 1 to 4, 4 to 6, and 4 to 6 in four-  
38  
39 year, eight-year, and 12-year service life, respectively. Taking eight to ten years into  
40  
41 consideration as the average service life of refrigerators in China (Liu et al., 2005), we  
42  
43 can see that the DIPP for more than one-half of the refrigerator pairs is within eight  
44  
45 years. As such, to some extent, the current subsidy policy contributed to encouraging  
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47 consumers to buy higher EEG-level refrigerators.  
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Fig. 3

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Fig. 4

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The economic benefits gap between EEG1 and EEG2, and between EEG2 and EEG3 was analysed by investigating the NPV difference and the DIPP in each pair in Group 1 and Group 2 respectively. Further investigation showed that EEG2 refrigerators yield larger economic benefits than EEG1 and EEG3 refrigerators, which indicated that most energy-efficient refrigerators are not cost-optimal choices for consumers. As shown in Table 2, in Group 1, the NPV difference in the first three pairs were negative in four scenarios, indicating that even though the refrigerators' service life lasts for 16 years, the economic benefits of EEG1 refrigerators are still lower than those of EEG2 refrigerators. For pair 1.4, although the NPV difference became positive in the 16-year service life scenario, the values under the 12-year scenario were negative. Drawing on this, the economic benefits for EEG1 refrigerators are still lower than those of EEG2 refrigerators if the service life is limited to 12 years; moreover, the EEG1 refrigerators' benefits can only exceed those of EEG2 refrigerators when their service life reaches 16 years. Compared with the first four pairs, pair 1.5 can first reach the positive NPV difference under the eight-year service life, meaning that EEG1 refrigerators can confer higher economic



1 benefits than EEG2 refrigerators from the eighth year. However, as we mentioned  
2  
3 above, the service life of refrigerators in China is normally from eight to ten years  
4  
5 (Liu et al.,2005), and our results reflect that for most consumers, EEG2 refrigerators  
6  
7 will confer more economic benefits than EEG1 refrigerators.  
8  
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10  
11 Table 2 indicates that the NPV difference in the first three pairs remained negative  
12  
13 for the four scenarios after obtaining the subsidy. For those refrigerators, subsidy  
14  
15 policy cannot change the fact that EEG2 refrigerators have higher economic benefits  
16  
17 than EEG1 refrigerators. On the contrary, for the other two pairs (1.4 and 1.5), the  
18  
19 DIPPs decreased significantly, indicating that the subsidy can increase the economic  
20  
21 benefits of EEG1 refrigerators; however, the economic benefits of EEG1 refrigerators  
22  
23 still cannot surpass those of EEG2 refrigerators in the presence of the subsidy. Even  
24  
25 when considering the use of 16 years as a standard for refrigerator service life, the  
26  
27 subsidy policy does not change the fact that EEG2 refrigerators in the first three pairs  
28  
29 (1.1, 1.2 and 1.3) and EEG1 refrigerators in the remaining two pairs (1.4 and 1.5)  
30  
31 have better economic benefits. If we use eight years as a standard for refrigerator  
32  
33 service life, only in pair 1.4 does the subsidy policy permit the economic benefits of  
34  
35 EEG1 refrigerators to exceed those of EEG2 refrigerators. In other words, the  
36  
37 influence of the subsidy policy is quite limited with respect to EEG1 refrigerators.  
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50 Group 2 demonstrated that most of the results can achieve a positive NPV  
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52 difference in the 16-year scenario even without a subsidy. EEG2 refrigerators can  
53  
54 have higher economic benefits than EEG3 refrigerators in the 16-year service life. If  
55  
56 the service life is limited to 12 years, there are still three pairs (2.1, 2.2 and 2.5) which  
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1 have a positive NPV difference. Furthermore, if we consider eight years for  
2 refrigerator service life, only two pairs with a positive NPV difference can be  
3 identified. Thus, EEG3 refrigerators can have higher economic benefits than EEG2  
4 refrigerators in three pairs.  
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10  
11 When examining the efficiency of the energy-efficient subsidy policy on Group 2  
12 refrigerators, we found that, in the 16-year scenario, four pairs refrigerators (2.1, 2.2,  
13 2.4 and 2.5) had a positive NPV difference in the absence and presence of subsidies.  
14 In this case, the subsidy policy had limited influence. However, when examining the  
15 efficiency of the policy in the 12-year and eight-year scenarios, the efficiency of the  
16 subsidy policy can be identified. For the 12-years scenario, the number of pairs with a  
17 positive NPV difference increases from three to four, whereas for the eight-year  
18 scenario, the number of pairs with a positive NPV difference increases from two to  
19 four. Therefore, for a long service life (e.g. 16 years), the subsidy policy worked less  
20 efficiently; whereas, for a shorter service life (e.g. 12 years, eight years), the  
21 efficiency of the subsidy policy emerged.  
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42 Drawing on these results, when we consider the service life as 16 years, a  
43 comparison of the NPV difference between EEG2 and EEG3 refrigerators indicates  
44 that the influence of the subsidy policy on consumers' decision making is limited, and  
45 that consumers can obtain higher economic benefits by purchasing EEG2 refrigerators  
46 in pairs 2.1, 2.2, 2.4 and 2.5, as well as by purchasing EEG3 refrigerators in pair 2.3.  
47 Only when we consider the service life as eight years does the subsidy policy change  
48 consumers' purchase decisions for higher EEG-level refrigerators in two pairs, 2.1  
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1 and 2.4. However, under the eight-year scenario, although the subsidy policy can  
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3 mainly influence consumers' purchase decisions on Group 2 refrigerators, its  
4  
5 influence on Group 1 refrigerators is quite weak and only consumers' purchase  
6  
7 decisions in pair 1.4 are changed.  
8  
9

### 10 11 12 13 14 *5.2 Scenario analysis of subsidy rate for EEG1 refrigerators* 15

16  
17 As our analysis revealed that the economic benefits of EEG2 refrigerators are  
18  
19 always generally higher than those of EEG1 and EEG3 refrigerators when considering  
20  
21 four different service life scenarios, we further investigated what subsidy rate is  
22  
23 appropriate for informing the development of a new subsidy policy.  
24  
25

26  
27  
28 Currently, EEG1 and EEG2 refrigerators dominate the Chinese refrigerator market,  
29  
30 while the EEG3 refrigerator market share is relatively low; thereby, we only  
31  
32 considered EEG1 and EEG2 refrigerators in our scenario analysis. Based on the  
33  
34 previous analysis, it was assumed that subsidy rates for EEG1 refrigerator were 13%,  
35  
36 15%, 17%, 19%, 21%, 23%, 24% and 25%, and that no subsidy was given to EEG2  
37  
38 refrigerators. Table 2 indicates that most EEG2 refrigerators can have higher  
39  
40 economic benefits than EEG3 refrigerators even without subsidies under 16 years of  
41  
42 service life. In other words, consumers are willing to purchase EEG2 rather than  
43  
44 EEG3 refrigerators regardless of the subsidy policy. In addition, we can identify from  
45  
46 Table 2 that even in the presence of subsidies, the economic benefits of most EEG1  
47  
48 refrigerators are still always lower than those of EEG2 refrigerators. Therefore, the  
49  
50 subsidy rate is considered to be higher than the current rate (13%). The relevant  
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1 results are shown in Table 3, in which the DIPP for each pair of refrigerators under  
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3 different subsidy rates are presented.  
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11 Table. 3  
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16  
17 Based on the government regulation that the maximum service life for household  
18 refrigerators should be no more than 16 years, we compared the DIPP within 16 years.  
19  
20 Table 3 indicates that when the rate is 13%, the DIPP of two pairs exceeds 16 years  
21 (1.1 and 1.3). When the rate increases to 19%, only the DIPP of one pair is more than  
22 16 years (1.1). When the rate further increases to 24%, all DIPPs are less than 16  
23 years. Moreover, we also calculated the results under 25.5% (not listed in Table 3) and  
24 found the longest period to be just 9.7, meaning that the DIPP for all pairs was less  
25 than 10 years. Our results show that if 24% subsidies are given to EEG1 refrigerators  
26 and subsidies for EEG2 refrigerators are removed, the economic benefits for EEG1  
27 refrigerators will be higher than those of EEG2 refrigerators in 16 years. If the  
28 subsidy rate increases to 25.5%, the economic benefits for EEG1 refrigerators will be  
29 higher than those of EEG2 refrigerators in less than ten years for all pairs.  
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49 *5.3 Discussion on subsidy policy implementation*  
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52 The policy evaluation implies that the current energy-efficient subsidy policy has  
53 been encouraging consumers to purchase more energy-efficient (EEG2) appliances  
54 instead of the most efficient (EEG1) alternatives. Drawing on the results, we conclude  
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1 that the current energy-efficient subsidy policy has not been implemented efficiently.

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3 Based on our analysis, we argue that future policy should adjust the subsidy strategies.

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6 Given the purchasing interests of EEG2 refrigerators, to allocate the policy more  
7  
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9 efficiently, the subsidy could be reduced in EEG2, but increased in EEG1 products.

10  
11 Based on the results of the economic benefits evaluation and scenario analysis, we  
12  
13 inform the government on policy adjustment strategy and argue that to bridge the  
14  
15 cost-effective gap between EEG1 and EEG2 refrigerators, the Chinese government  
16  
17 can cancel the subsidies for EEG2 refrigerators and increase the subsidy rate of EEG1  
18  
19 refrigerators from 13% to 24%. The current subsidy rate for EEG1 and EEG2  
20  
21 refrigerators is 13% and 8% respectively, by assuming that same price is set for EEG1  
22  
23 and EEG2 refrigerators, the difference between the current subsidy rate and our target  
24  
25 subsidy rate is just 3% ( $24\% - 13\% - 8\%$ ). This means that the cost for increasing the  
26  
27 subsidy rate for EEG1 will not significantly increase the government budget. In  
28  
29 addition, the results of scenario analysis indicate that when the subsidy rate is up to 24%  
30  
31 for EEG1 refrigerators, the sampled EEG1 refrigerators can have higher economic  
32  
33 benefits than EEG2 refrigerators under 16-year service life, meaning that the  
34  
35 electricity consumption cost saved by EEG1 refrigerators within the service life can  
36  
37 compensate the price difference between EEG1 and EEG2 refrigerators. With the  
38  
39 increase of subsidy on EEG1 refrigerators, more households can afford the initial  
40  
41 investment (Matosović and Tomšić, 2018), and that can potentially persuade  
42  
43 consumers to switch their buying preference of EEG2 refrigerators to EEG1 ones to  
44  
45 ultimately achieve the government's energy-saving goal.  
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## 6. Conclusion and policy implications

The novel contribution of this study is to evaluate the efficiency of Chinese current energy-efficient household appliance subsidy policy and inform government's redesign of the subsidy policy to improve efficiency. To conduct the evaluation, we quantified the policy efficiency by selecting ten pairs of refrigerators with a similarity in functions but different EEG levels, and the conversion method of electrical engineering coefficient was adopted to make refrigerators with different EEG levels in pairs comparable. By adopting the perspective of the entire lifecycle NPV difference, this study measured the economic benefits of ten pairs of refrigerators in four scenarios to evaluate the policy's efficiency: 4-year, 8-year, 12-year and 16-year service life in the absence and presence of subsidies. The results revealed that economic benefits were mainly generated in EEG2; thereby we suggest that the government can cancel subsidies for EEG2 refrigerators, and increase the subsidy amount for EGG1 refrigerators.

Relevant policy implications are provided by this study. First, central and regional governments can reexamine their policy efficiency in design and implementation, taking advantages from the findings of this study. Second, for the case of efficiency improvement, governments can consider policy adjustment. Generic subsidies may weaken consumers' preference for the most energy-efficient household appliances, which is not consistent with the original goal of the energy-efficient subsidy policy. Our study argues that direct subsidies for the most energy-efficient household

1 appliances would be more efficient. Third, due to the large price gap between  
2  
3 household appliances with an EEG1 level and those with an EEG2 level, increasing  
4  
5 the subsidy for EEG1 appliances is strongly recommended for the Chinese  
6  
7 government. Based on our study, the subsidy rate on household appliances with an  
8  
9 EEG1 level should be raised up to 24%, which is fairly higher than the current  
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11 subsidy rate of 13%. In addition to energy efficiency subsidies, more rational  
12  
13 information strategies in policy implementation can also lead to energy-saving actions.  
14  
15 The results of our study show that the NPV of a product can suitably reflect the  
16  
17 aggregate economic cost of the entire life cycle of the product, which is beyond the  
18  
19 consumers' knowledge and awareness. Adding more accurate economic cost  
20  
21 information to the existing energy-efficiency information can effectively motivate  
22  
23 consumers to purchase energy-efficient products (Davis and Metcalf, 2016). It is  
24  
25 concluded that combining more precise subsidy policies and more effective  
26  
27 information policies will greatly promote energy-saving behaviour in the Chinese  
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29 household sector.  
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42 This study is shed the light on the analysis of economic benefits, which then draws  
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44 upon concrete results and discussions, meanwhile the scope of focus could limit the  
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46 consideration of other factors affecting consumers' purchasing decisions, apart from  
47  
48 the economic benefits. In future studies, psychological elements, information, and  
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50 regulation factors as mentioned in the literature review can be further combine with  
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52 economic factors to quantitatively analyse consumers' decisions on purchasing  
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54 energy-efficient products.  
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62  
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65





- 1 Carroll, J., Denny, E., Lyons, S., 2016. The effects of energy cost labelling on  
2  
3 appliance purchasing decisions: Trial results from Ireland. *Journal of Consumer*  
4  
5  
6 Policy 39, 23-40.  
7  
8  
9 Chen, Y.J., Zuo, Y., 2018. Research on price elasticity and cross-subsidy of industrial  
10  
11 and residential power users. *China Price* (07), 56-59. (in Chinese)  
12  
13  
14 Cohen, F., Glachant, M., Söderberg, M., 2017. Consumer myopia, imperfect  
15  
16 competition and the energy efficiency gap: Evidence from the UK refrigerator  
17  
18 market. *European Economic Review* 93, 1-23.  
19  
20  
21  
22 Datta, S., Gulati, S., 2014. Utility rebates for ENERGY STAR appliances: Are they  
23  
24 effective? *Journal of Environmental Economics and Management* 68(3), 480-506.  
25  
26  
27  
28 Davis, L. W., Metcalf, G. E., 2016. Does Better Information Lead to Better Choices?  
29  
30 Evidence from Energy-Efficiency Labels. *Journal of the Association of*  
31  
32 *Environmental and Resource Economists*, 3(3), 589-625.  
33  
34  
35  
36 Ek, K., Söderholm, P., 2010. The devil is in the details: Household electricity saving  
37  
38 behavior and the role of information. *Energy Policy* 38, 1578-1587.  
39  
40  
41  
42 Enongene, K.E., Murray, P., Holland, J., Abanda, F.H., 2017. Energy savings and  
43  
44 economic benefits of transition towards efficient lighting in residential buildings  
45  
46 in Cameroon. *Renewable and Sustainable Energy Reviews* 78, 731-742.  
47  
48  
49  
50 Feng, D.S., Sovacool, B.K., Vu, K.M., 2010. The barriers to energy efficiency in China:  
51  
52 Assessing household electricity savings and consumer behavior in Liaoning  
53  
54 Province. *Energy Policy* 38, 1202-1209.  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 estimated level of underlying energy efficiency in the EU residential  
2  
3 sector. Energy policy 69, 73-81.  
4

5  
6 Fuerst, F., Singh, R., 2018. How present bias forestalls energy efficiency upgrades: A  
7  
8 study of household appliance purchases in India. Journal of Cleaner Production  
9  
10 186 , 558-569.  
11

12  
13 Galarraga, I., González-Eguino, M., Markandya, A.,2011. Willingness to pay and  
14  
15 price elasticities of demand for energy-efficient appliances: Combining the  
16  
17 hedonic approach and demand systems. Energy Economics 33, 66-74.  
18  
19

20  
21 Gerarden, T. D., Newell, R. G., Stavins, R. N., 2017. Assessing the energy-efficiency  
22  
23 gap. Journal of Economic Literature 55(4), 1486-1525.  
24  
25

26  
27 Gillingham, K., Newell, R.G., Palmer, K., 2009. Energy Efficiency Economics and  
28  
29 Policy. Annual Review of Resource Economics 1, 597-620.  
30  
31

32  
33 Gillingham, K., Palmer, K., 2014. Bridging the energy efficiency gap: Policy insights  
34  
35 from economic theory and empirical evidence. Review of Environmental  
36  
37 Economics and Policy 8(1), 18-38.  
38  
39

40  
41 Gov. cn, 2015.GB12021.2-2015 The maximum allowable values of the energy  
42  
43 consumption and energy efficiency grade for household  
44  
45 refrigerators.<[www.sac.gov.cn](http://www.sac.gov.cn)>(18.09.2015)  
46  
47

48  
49 Gov. cn., 2019.The circular on the implementation plan for further optimizing supply  
50  
51 to promote steady growth of consumption and the formation of a strong domestic  
52  
53 market (2019) was issued<[http://www.gov.cn/xinwen/2019-](http://www.gov.cn/xinwen/2019-01/29/content_5361940.htm)  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 Gram-Hanssen, K., Bartiaux, F., Jensen, O.M., Cantaert, M., 2007. Do home owners  
2  
3 use energy labels? A comparison between Denmark and Belgium. *Energy Policy*  
4  
5  
6 35, 2879-2988.  
7  
8  
9 Horngren, C.T., Sundem, G.L., Schatzberg, J.O., Burgstahler, D., 2013. Introduction to  
10  
11 management accounting. Pearson Higher Ed.  
12  
13  
14 Hu, J., 2009. Presentation at climate change summit meeting in New York.  
15  
16  
17 IEA, 2009. Implementing energy efficiency policies: are IEA member countries on  
18  
19 track? OECD/IEA, Paris.  
20  
21  
22 Jeong, G.C., Kim, Y.J., 2015. The effects of energy efficiency and environmental  
23  
24 labels on appliance choice in South Korea. *Energy Efficiency* 8, 559–576.  
25  
26  
27 Jia, J.J., Xu, J.H., Fan, Y., Ji, Q., 2018. Willingness to accept energy-saving measures  
28  
29 and adoption barriers in the residential sector: An empirical analysis in Beijing,  
30  
31 and adoption barriers in the residential sector: An empirical analysis in Beijing,  
32  
33 China. *Renewable and Sustainable Energy Reviews* 95: 56-73.  
34  
35  
36 Ji, Q., Li, J., Sun, X., 2019. New Challenge and Research Development in Global  
37  
38 Energy Financialization. *Emerging Markets Finance and Trade* 55, 2669-2672.  
39  
40  
41 Kallbekken, S., Sælen, H., Hermansen, E. A., 2013. Bridging the energy efficiency  
42  
43 gap: A field experiment on lifetime energy costs and household  
44  
45 appliances. *Journal of Consumer Policy* 36(1), 1-16.  
46  
47  
48 Li, J., Zhang, J., Zhang, D., Ji, Q., 2019. Does gender inequality affect household  
49  
50 green consumption behaviour in China? *Energy Policy* 135, 111071.  
51  
52  
53 Linares, P., Labandeira, K., 2010. Energy Efficiency: Economics and Policy. *Journal*  
54  
55  
56  
57  
58 of Economic Surveys 24, 573-592.  
59  
60  
61

- 1 Liu,X.L., Yang,J.X., Wang, R.S., 2005. Estimation of WEEE generation in China.  
2  
3 China Population, Resources and Environment (05), 117-121. (in Chinese)  
4  
5  
6 Li, Y., Ji,Q., Zhang, D., 2020. Technological catching up and innovation policies in  
7  
8 China: What is behind this largely successful story? Technological Forecasting  
9  
10 and Social Change 153, 119918.  
11  
12  
13  
14 Ma, G., Andrews-Speed, P., Zhang, J., 2013. Chinese consumer attitudes towards  
15  
16 energy saving: The case of household electrical appliances in Chongqing. Energy  
17  
18 Policy56, 591-602.  
19  
20  
21  
22 Matosović, M., Tomšić, Ž., 2018. Modeling energy efficiency investment choices – a  
23  
24 case study on Croatia’s residential sector. Energy Sources, Part B: Economics,  
25  
26 Planning, and Policy13(7), 311-319.  
27  
28  
29  
30  
31 Mills, B., Schleich, J., 2010. What’s driving energy efficient appliance label  
32  
33 awareness and purchase propensity?. Energy Policy 38, 814-825.  
34  
35  
36  
37 Nie, H., Vasseur, V., Fan, Y., Xu, J., 2019. Exploring reasons behind careful-use,  
38  
39 energy-saving behavioursinresidential sector based on the theory of planned  
40  
41 behaviour: Evidencefrom Changchun, China. Journal of Cleaner Production 230,  
42  
43 29-37.  
44  
45  
46  
47 Panzone, L.A., 2013. Saving money vs investing money: Do energy ratings influence  
48  
49 consumer demand for energy efficient goods?. Energy Economics 38, 51-63.  
50  
51  
52  
53 Parry, I. W., Evans, D., Oates, W. E., 2014. Are energy efficiency standards  
54  
55 justified?. Journal of Environmental Economics and Management 67(2), 104-125.  
56  
57  
58  
59 Shaikh, F., Ji, Q., Fan, Y., 2015. The diagnosis of an electricity crisis and alternative  
60  
61  
62  
63  
64  
65

1 energy development in Pakistan. *Renewable and Sustainable Energy Reviews*  
2  
3 52,1172-1185.  
4  
5

6 Shen,J.Y., Saijo, T., 2009. Does an energy efficiency label alter consumers'  
7  
8 purchasing decisions? A latent class approach based on a stated choice  
9  
10 experiment in Shanghai. *Journal of Environmental Management* 90, 3561-3573.  
11  
12

13 Stadelmann, M., Schubert, R., 2018. How Do Different Designs of Energy Labels  
14  
15 Influence Purchases of Household Appliances? A Field Study in Switzerland.  
16  
17  
18  
19  
20  
21  
22  
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Ecological Economics 144, 112-123.  
Tao, J., Yu, S., 2011. Implementation of energy efficiency standards of household  
refrigerator/freezer in China: Potential environmental and economic  
impacts. *Applied Energy* 88(5), 1890-1905.

Tietenberg, T. 2009. Reflections: Energy efficiency policy: A pipe dream or a pipeline  
to the future? *Review of Environmental Economics and Policy* 3(2): 304–20.

Toutiao.com,2019. South China Gome fully opened the energy-saving subsidy policy  
for home appliances. <<https://www.toutiao.com/i6676727867549680141/>>  
(06.04.2019).

Wang,Z.H., Wang, X.M., Guo, D.X.,2017. Policy implications of the purchasing  
intentions towards energy-efficient appliances among China's urban residents:  
Do subsidies work?. *Energy Policy* 102, 430-439.

Wu, J., Lv, L., Sun, J., Ji, X., 2015. A comprehensive analysis of China's regional  
energy saving and emission reduction efficiency: From production and treatment  
perspectives. *Energy Policy* 84, 166-176.

- 1 Xia, Y., Kong, Y., Ji, Q., Zhang, D., 2019. Impacts of China-US trade conflicts on the  
2  
3 energy sector. *China Economic Review* 58, 101360.  
4  
5
- 6 Xie, B. C., Zhao, W., 2018. Willingness to pay for green electricity in Tianjin, China:  
7  
8 Based on the contingent valuation method. *Energy Policy* 114: 98-107.  
9  
10
- 11 Xu, X., Wei, Z., Ji, Q., Wang, C., Gao, G., 2019. Global renewable energy  
12  
13 development: influencing factors, trend predictions and countermeasures.  
14  
15  
16  
17 *Resources Policy* 63, 101470.  
18  
19
- 20 Yu, Q.W., Chen, L.P., Guo, H.T., 2012. Analysis on consumption of energy-saving  
21  
22 electric appliances and energy-saving effect among Beijing urban households.  
23  
24  
25 *Journal of Beijing Technology and Business University (Social Science)* 27(06),  
26  
27  
28 96-103. (in Chinese)  
29  
30
- 31 Yu, S., Zheng, S., Zhang, X., Gong, C., Cheng, J., 2018. Realizing China's goals on  
32  
33 energy saving and pollution reduction: Industrial structure multi-objective  
34  
35 optimization approach. *Energy Policy* 122, 300-312.  
36  
37  
38
- 39 Yu, Y.H., Guo, J., 2016. Identifying electricity-saving potential in rural China:  
40  
41 Empirical evidence from a household survey. *Energy Policy* 94, 1-9.  
42  
43  
44
- 45 Yuan, C., Liu, S., Fang, Z., Wu, J., 2009. Research on the energy-saving effect of  
46  
47 energy policies in China: 1982-2006. *Energy Policy* 37, 2475-2480.  
48  
49
- 50 Yuan, J.H., Hou, Y., Xu, M., 2012. China's 2020 carbon intensity target: Consistency,  
51  
52 implementations, and policy implications. *Renewable and Sustainable Energy*  
53  
54  
55  
56 *Reviews* 16, 4970-4981.  
57  
58
- 59 Zhao, X., Li, H., Wu, L., Qi, Y., 2014. Implementation of energy-saving policies in  
60  
61  
62  
63  
64  
65

1 China: How local governments assisted industrial enterprises in achieving  
2  
3 energy-saving targets. *Energy Policy* 66, 170-184.  
4

5  
6 Zhou, H., Bukenya, J.O., 2016. Information inefficiency and willingness-to-pay for  
7  
8 energy-efficient technology: A stated preference approach for China Energy  
9  
10 Label. *Energy Policy* 91, 12-21.  
11  
12

13  
14 Zhou, M., Zhen, W.T., 2018. Life cycle sustainability assessment of new energy  
15  
16 vehicles and traditional automobiles. *Enterprise Economy* (01), 129-134. (in  
17  
18 Chinese)  
19  
20

21  
22 Zhou, N., Levine, M.D., Price, L., 2010. Overview of current energy-efficiency  
23  
24 policies in China. *Energy Policy* 38, 6439-6452.  
25  
26

27  
28 Zhou, N., Fridley, D., McNeil, M., Zheng, N., Letschert, V., Ke, J., Saheb, Y., 2011.  
29  
30 Analysis of potential energy saving and CO2 emission reduction of home  
31  
32 appliances and commercial equipments in China. *Energy Policy* 39, 4541-4550.  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
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**Appendix A**

**Weighting coefficient  $W_C$  of each type of refrigerator**

Compartment type	Cold room	Cooling room	Ice greenhouse	Ice making room	0 star room	1 star room	2 star room	3 star room	4 star room	Wine storage room
$T_C/^\circ\text{C}$	4	12	2	0	0	-6	-12	-18	-18	12
$W_C$	1.00	0.65	1.15	1.25	1.25	1.55	1.85	2.15	2.15	0.65

For the compartment type not included in the table, the weighting factor  $W_C$  is calculated according to the formula:

$$W_C = \frac{25 - T_C}{20}$$

$T_C$ ----The design temperature of a type of compartment, or the characteristic temperature specified by the manufacturer, in degrees Celsius ( $^\circ\text{C}$ )



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**Appendix B**

**Energy efficiency index conversion of refrigerator energy efficiency rating**

<b>Energy efficiency rating</b>	Refrigerated freezer	Wine storage cabinet	Horizontal refrigerated freezer	Other types
	Standard energy	Standard energy	Standard energy	Standard energy
	efficiency index $\eta_a$	efficiency index $\eta_a$	efficiency index $\eta_a$	efficiency index $\eta_a$
1	$\eta_a \leq 25\%$	$\eta_a \leq 55\%$	$\eta_a \leq 35\%$	$\eta_a \leq 45\%$
2	$25\% < \eta_a \leq 35\%$	$55\% < \eta_a \leq 70\%$	$35\% < \eta_a \leq 45\%$	$45\% < \eta_a \leq 55\%$
3	$35\% < \eta_a \leq 50\%$	$70\% < \eta_a \leq 80\%$	$45\% < \eta_a \leq 55\%$	$55\% < \eta_a \leq 65\%$
4	$50\% < \eta_a \leq 60\%$	$80\% < \eta_a \leq 90\%$	$55\% < \eta_a \leq 65\%$	$65\% < \eta_a \leq 75\%$
5	$60\% < \eta_a \leq 70\%$	$90\% < \eta_a \leq 100\%$	$65\% < \eta_a \leq 75\%$	$75\% < \eta_a \leq 85\%$

**Table 1**

Specific parameters of the sample refrigerators

<b>Group 1</b>	<b>Brand</b>	<b>Model</b>	<b>EEG</b>	<b>Price (¥)</b>	<b>Power (KW.h)</b>	<b>Refrigeration compartment volume (L)</b>	<b>Temperature-vari- ble compartment volume (L)</b>	<b>Freezer compartment volume (L)</b>	<b>Climate type</b>	<b>Number of doors</b>	<b>Embedded</b>	<b>Frost-free refrigerator</b>
1.1	Haier	BCD- 328WDPD	1	3899	0.65	181	30	117	T	4	YES	YES
		BCD- 520WDPD	2	4399	0.98	324	24	172	T	2	YES	YES
1.2	Haier	BCD-217WDVLU1	1	3299	0.58	117	29	71	T	3	YES	YES
		BCD-258WDVLU1	2	3299	0.69	144	40	74	T	3	YES	YES
1.3	Midea	BCD-230WTPZM(E)	1	3399	0.51	116	40	74	T	3	NO	YES
		BCD-228WTPZM(E)	2	2499	0.60	119	38	71	T	3	NO	YES
1.4	Midea	BCD-326WGPZM	1	4699	0.59	176	32	118	T	3	YES	YES
		BCD-320WGPZM	2	3799	0.95	185	111	24	T	4	YES	YES
1.5	Hisense	BCD-629WTVBP/Q	1	3899	0.99	406	-	223	T	2	YES	YES
		BCD-535WTVBP/Q	2	2999	1.09	346	-	189	T	2	YES	YES

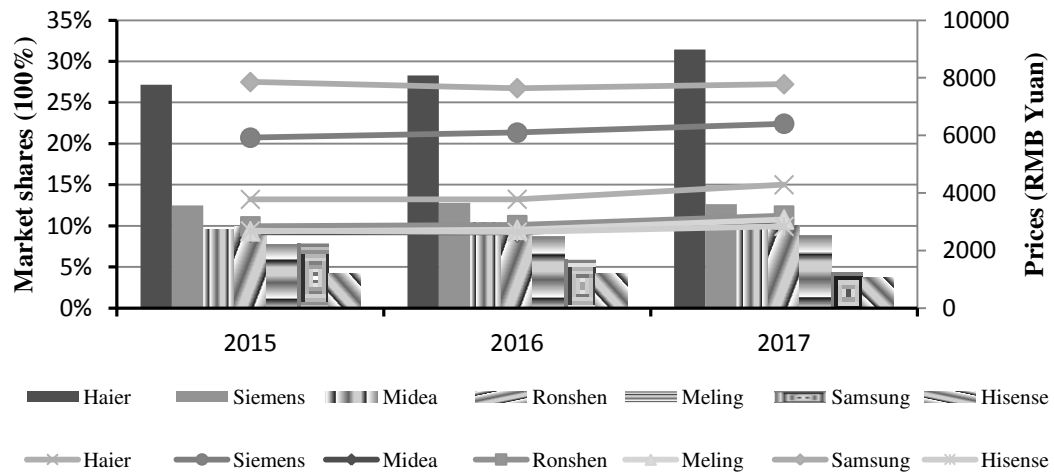
Group 2	Brand	Model	EEG	Price (¥)	Power (KW.h)	Refrigeration chamber volume (L)	Changing greenhouse / star volume (L)	Freezer compartment volume (L)	Climate type	Number of doors	Embedded	Frost-free refrigerator
2.1	Haier	BCD-189WDPV	2	1899	0.70	120	-	69	ST	2	NO	YES
		BCD-149WDPV	3	1439	0.66	95	-	54	ST	2	NO	YES
2.2	Ronshen	BCD-217D11N	2	1499	0.51	118	-	99	ST	3	YES	NO
		BCD-218D11N	3	1399	0.63	119	-	99	ST	3	YES	NO
2.3	Ronshen	BCD-590WD11HY	2	4399	1.14	379	-	211	ST	2	YES	YES
		BCD-526WD11HY	3	2899	1.24	337	-	189	ST	2	YES	YES
2.4	Meling	BCD-205WECX	2	2499	0.56	137	-	68	ST	2	YES	YES
		BCD-185WECX	3	1899	0.68	123	-	62	ST	2	YES	YES
2.5	Konka	BCD-551WEGX5S	2	2999	1.21	360	25	166	T	2	YES	YES
		BCD-430WEGX5S	3	2299	1.39	275	20	135	T	2	YES	YES

**Table 2**

NPV difference and DIPP in absence and presence of subsidy in each scenario

Group	Without energy saving subsidy policy					With energy saving subsidy policy				
	4	8	12	16	DIPP(Year)	4	8	12	16	DIPP(Year)
1.1	-1066.45	-1014.59	-968.06	-926.32	>30	-781.56	-729.70	-683.17	-641.43	>30
1.2	-479.97	-440.23	-404.58	-372.60	>30	-273.08	-233.34	-197.69	-165.71	>30
1.3	-805.26	-739.93	-681.32	-628.74	>30	-565.07	-499.74	-441.13	-388.54	>30
1.4	-537.73	-276.42	-41.97	168.36	12.77	-236.46	24.85	259.30	469.63	7.60
1.5	-168.13	15.73	180.69	328.68	7.64	56.66	240.53	405.48	553.48	2.85
2.1	-45.85	-20.59	2.07	22.39	11.62	106.07	131.33	153.99	174.31	0
2.2	-9.92	70.90	143.41	208.46	4.47	110.00	190.82	263.30	328.38	0
2.3	-987.37	-843.92	-715.22	-599.75	>30	-635.45	-492.00	-363.30	-247.83	26.41
2.4	-276.84	-171.10	-76.24	8.87	15.57	-76.92	28.82	123.68	208.79	6.87
2.5	282.49	583.54	853.63	1095.95	0.61	522.41	823.46	1093.55	1335.87	0





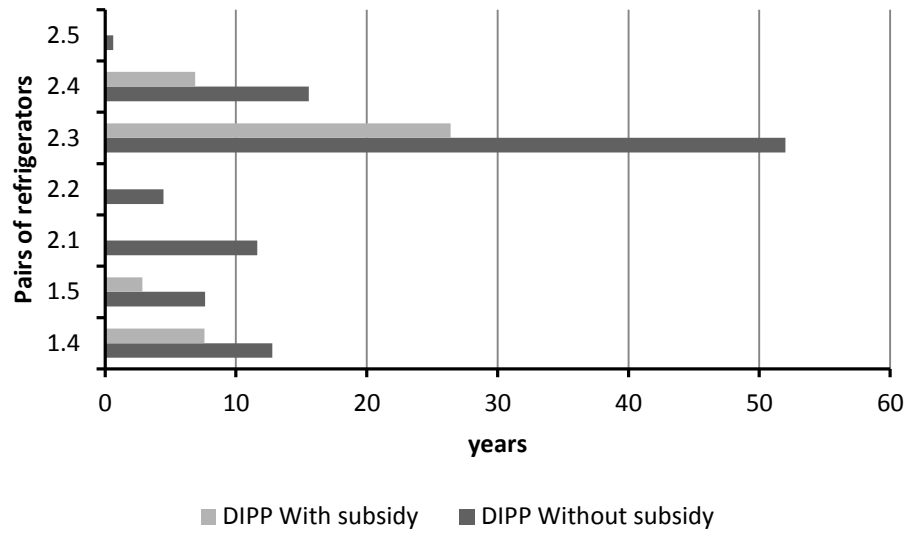
**Fig.1** Market shares and average prices of the top 7 refrigerator brands in China from 2015 to 2017 (based on sales). Note: The bar and line corresponds to the market share of the main axis and the price of the secondary axis respectively.

Data sources: <http://www.jiadian.com.cn/2019/199/>



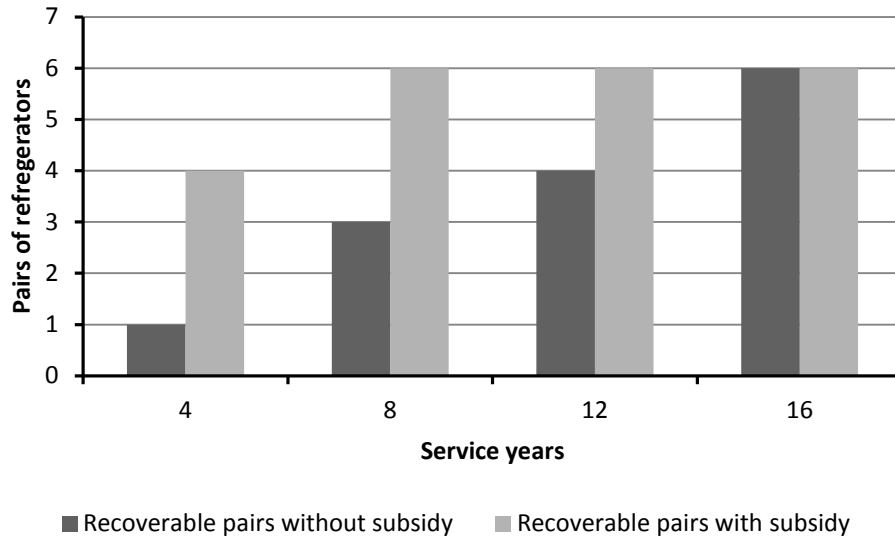
■ Haier   ■ Midea   ≡ Siemens   ■ Ronshen  
▨ Meling   ▩ Panasonic   ▩ Konka   ■ Samsung

**Fig.2** Market shares of the top 7 refrigerator brands in China in 2018 (based on sales volume). Data sources: <http://www.avc-mr.com/>



**Fig.3** The DIPP for Partial samples in absence and presence of subsidy





**Fig.4** The number of refrigerator pairs in which investment differentials are recoverable

## Highlights

The main findings of this study could be highlighted as:

- China's energy-saving subsidy policy does not reduce the purchasing price for refrigerators.
- Refrigerators at EEG2 have higher economic benefits than EEG1 ones regardless the subsidy policy.
- The influence of the policy on purchasing preference is depended on the products' service life.
- Government needs to adjust the weight of subsidy at different levels to improve policy efficiency.

## **Credit Author Statement**

Each author's contributions could be outline as follow:

**Hongguang Nie:** Framing the original ideas, conceptualization, funding acquisition, supervision

**Ting Zhou:** data collection, analysis

**Haiyan Lu:** Reshaping the discussions and contributions of the paper, Writing, reviewing, editing, funding acquisition,

**Shupeng Huang:** assisting data analysis