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RESEARCH ARTICLE

Determinants of household energy efficiency investment: analysis of refrigerator purchasing behavior

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Abstract

Previous studies have reported that households tend to not choose an energy-efficient appliance even if appropriate energy-saving information is provided. To identify the determinants of energy efficiency investment, we conducted a household survey in the Tokyo metropolitan area. Specifically, we collect product model information for the refrigerator that a household owns and calculate the yearly loss incurred from choosing a less efficient model. We then identify socioeconomic characteristics of households that are associated with these yearly losses. We find that wealthy households with many family members tend to purchase inefficient models. We also find that a house-renter with a high income is more likely to purchase an energy-inefficient model. A program targeted at such households could be effective for increasing energy savings in the residential sector.

Keywords Energy efficiency · Household · Micro data · Refrigerator

JEL Classification H31 · D12 · Q48

Introduction

Many countries have implemented various measures to improve the energy efficiency of home electric appliances. Such measures include establishing minimum energy-efficiency standards for certain appliances and requesting manufacturers to

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reduce the energy consumption of their products [11]. With the implementation of a minimum energy efficiency standard, sales of very inefficient appliances can be prohibited, and the efficiency of domestic energy usage is expected to gradually improve through replacement of older less-efficient appliances. For example, the U.S. Environmental Protection Agency (EPA) introduced the Energy Star program to help households to choose energy-efficient products [25]. This program helps consumers determine the energy efficiency of appliances simply by counting the number of stars on the product. In contrast, manufactures in Japan estimate the annual energy usage of appliances under certain usage conditions, and retail stores display the expected annual electricity bill for each appliance. This allows Japanese consumers to compare the cost and benefit of energy-efficient appliances prior to purchase.

Previous studies have pointed out that households tend to not choose an energy-efficient product even if appropriate energy-saving information is provided (Allocott 2011). This has been attributed to a typical consumer underestimating the benefit of future energy saving, compared with the upfront cost necessary for the purchase of energy-efficient products. The phenomena of underinvestment in energy efficiency is called the "energy efficiency gap" and has been repeatedly pointed out in the academic literature [14, 18]. Although the magnitude of this energy-efficiency gap varies across households, factors associated with the gap have not been fully elucidated. Accordingly, the purpose of this study is to identify the determinants of energy-efficiency investment by examining the relationship between the energy efficiency of a household's current refrigerator and household characteristics.

An appliance's energy consumption depends on its energy efficiency as well as intensity of usage. If a consumer expects that an appliance will be used less intensively, then an energy-efficient model will not be purchased. On the other hand, when consumers expect to use an appliance intensively, then they will purchase an energy-efficient model. Therefore, the energy-efficiency investment decision is positively correlated with the intensity of appliance use. Household characteristics not only determine the intensity of appliance use, they also determine appliance selection. For instance, young couples tend to purchase a small energy-efficient appliance and uses it less frequently because they spend more time outside. In general, we need to understand the intensity of appliance usage to evaluate whether a household is making an energy-efficient investment properly. In contrast, use of refrigerators is not greatly affected by household characteristics. Households are expected to use the same refrigerator in a very similar way, e.g., most households have the refrigerator running on a constant basis. This distinctive feature of refrigerators greatly simplifies the discussion of energy-efficiency investment.

There are several additional advantages of using refrigerators for this analysis. Since a typical household owns only one refrigerator at home, we can focus on the energy efficiency of a single appliance. In contrast, a typical household owns multiple air conditioners (ACs), and thus we would need to consider the relative intensity of their use as well as their relative energy efficiency. Second, households spend a relatively substantial amount of money when purchasing a refrigerator. For instance, the price of the best-selling refrigerator was about JPY 156,000 on June 18, 2018 based on data from Kakaku.com [19], which corresponds to 4.6% of the average

household's annual consumption expenditure (Statistics Bureau of Japan 2018). Households use a fairly high amount of electricity running a refrigerator. According to a survey by the Ministry of Economy, Trade and Industry [24], a refrigerator uses approximately 12.3% of a household's total electricity consumption in Japan. Therefore, households are likely to seriously consider energy efficiency when purchasing a new refrigerator.

Given these aforementioned features of refrigerators, we focus on the energy efficiency of refrigerators in this study. Although the relationship between household characteristics and energy-efficiency investment has been analyzed in previous studies, detailed information about the energy efficiency of appliances has not been available. We conducted a survey to collect product model information for the refrigerator that households actually own. By combining detailed model information and household characteristics, we identify the factors that reduce the likelihood of purchasing energy-efficient appliances.

The remainder of the paper is organized as follows. Section 2 provides relevant information on household energy efficiency investment activities from related studies. In this study, we use the data obtained from an original survey. In Sect. 3, we explain the survey methodology and summarize the data. In Sect. 4, we specify the empirical model and report the empirical findings. We find that wealthy households living with many family members tend to purchase a less-efficient refrigerator. A middle-age household is more likely to purchase an efficient model than young or elderly households. A home-owner is more likely to purchase an energy-efficient model than a renter. Section 5 reports the conclusions and policy implications.

Related studies

Why do households choose inefficient appliances when they can lower their energy bill and save money in the long run with energy-efficient appliances? There has been a long-standing debate over why economic agents underinvest in energy-efficient technology. In this section, we will review the existing literature concerning household energy-efficiency investment.

Under perfect information, economic agents are expected to behave rationally and invest in energy saving technology if the long-term savings exceed the upfront costs. In reality, however, economic agents tend to underinvest in energy-saving technology, which has been termed the energy-efficiency gap [14, 18]. Jaffe and Stavins [18] provide three reasons for the energy efficiency gap: bounded rationality of households, information asymmetry, and high implicit discount rates.

The bounded rationality hypothesis states that households systematically reduce the choice problem, with respect to household-specific preferences. Then, the household chooses the good that maximizes their utility from the reduced choice set. Thus, the household does behave rationally, but their process of reducing the choice set eliminates the "optimal" choice.

The second reason for the energy-efficiency gap is the presence of asymmetric information. This hypothesis states that it is difficult for the household to collect relevant information concerning the products' energy efficiency and future energy costs. For

instance, Allcott [1] concluded that consumers tend to rely on current prices to forecast future prices. In other words, energy prices are expected to be the same in the future. However, it is possible that this forecast underestimates real future prices, which may increase due to environmental regulations such as carbon pricing. Thus, the household is unable the accurately calculate the long-term benefits of energy-efficient durables.

The final reason for the energy-efficiency gap is the high implicit discount rate compared to the social discount rate. This implies that the household are willing to invest in energy efficiency if the rate of return is higher than the market rate of return. Hausman [15] calculated that the implicit discount rate for air conditioners was approximately 20%. Ruderman et al. [30] found similar implicit discount rates for air conditioners, but a higher discount rate for refrigerators (78–105%). References [6, 13, 21, 29] also find high discount rates ranging from 34 to 300% for refrigerators. On the other hand, Cohen et al. [5] and Tsventanov and Sergerson (2014) find smaller discount rates ranging from 10.5 to 19.0% for refrigerators.

A recent study by Houde [17], focusing on the US refrigerator market, uses micro-level panel data to investigate how households respond to energy costs. He finds that lower-income households have higher discount rates. This finding is in line with the finding of Train [27], where the implicit discount rate decreased as income increased. Therefore, household income seems to be related to the purchase of energy-efficient appliances.

O'Doherty et al. [22] and Leahy and Lyon [20] use different approaches to try to identify the household characteristics that increases the probability of possessing energy-efficient appliances. Both studies find that household location, income, occupation, and number of family member affects the purchase of energy-efficient appliances. Similarly, Davis [8] finds that homeowners have a higher probability of possessing energy star-certified home appliances than their non-homeowning counterparts.

In any case, regulatory intervention is justified in the presence of market failures, including the energy-efficiency gap. One method of intervention is setting energy-efficiency standards. Hausman and Joskow [16] justify the role of energy-efficiency standards, which increase the average energy efficiency of products sold on the market, by identifying four market failures: energy prices without the full marginal social cost, underestimation of energy prices, high discount rates, and the principle-agent problem.

The existing literature discussed above has focused on the relationship between household characteristics and energy-efficiency investment. However, detailed information about the energy efficiency of a household's appliances and its characteristics have not been analyzed. Thus, we will focus on the refrigerator market in Japan and delineate the relationship between energy efficiency and household characteristics.

Data

Survey methodology

The data used in this study were collected by a specialized internet survey firm, Nippon Research Center. Monitors of the Nippon Research Center living within

the 30 km radius of Tokyo station, were randomly recruited as respondents of the survey. The survey was conducted from Thursday, October 15, 2015, through Friday, October 16, 2015. We focused on married men and women aged between 25 and 64 years. We targeted specific respondents in advance so as to eliminate bias in gender/age.

In the survey, households were asked to provide information about their characteristics and the model number of their refrigerator. We obtained complete information from a total of 159 respondents. When evaluating the energy efficiency of home appliances, previous studies used vintage of home appliances [28] or its receipt of an Energy Star label [9, 17, 26]. Although it is reasonable to assume that the energy efficiency of a new appliance is higher than that of an older appliance, vintage is not perfectly correlated with energy efficiency. In addition, energy efficiency varies greatly among appliances having the same Energy Star label. Therefore, both vintage and Energy Star ranking used in the previous studies can include measurement errors. In contrast, model number as used in this study provides precise information about energy efficiency. By using the model number information, we can investigate more precisely how household characteristics affect their energy-efficiency investment.

Data summary

Evaluation of refrigerator energy efficiency

Table 1 presents the number and market share of refrigerators newly released in the summer of 2011 and 2015, according to the number of the Energy Star labels [3]. The table shows that the share of 5-star models increased from 21% in 2011 to 48% in 2015. It further shows that almost all refrigerators with a capacity greater than 401 L are 5-star models.

Table 2 uses the data from the original survey conducted for this study and examines the share of the households who own a 5-star model. Although 103 out of 159 households own 5-star models, only 22 households selected the most efficient model at the time of purchase. This result suggests that it is not sufficient to discuss household energy- efficiency investment simply by examining whether or not a household owns an Energy Star model.

As mentioned earlier, the use of a refrigerator is not greatly affected by household characteristics. On the other hand, the selection of a refrigerator will be affected by these characteristics. Households use a refrigerator to store food, and accordingly, refrigerators are mainly characterized by two attributes: capacity and energy efficiency. If households want to preserve more food, then they need to purchase a large-capacity model. If households want to save on future electricity bills, then they need to purchase an energy-efficient model.

If households decided to purchase a less-efficient model, then they will pay for additional electricity, compared with households who choose more-efficient models. In this study, we calculate the additional electricity cost arising from the purchase of a less-energy-efficient models, which we define as yearly loss.

Table 1 Number and share of refrigerators released in years 2011 and 2015

Energy star label	2011 Summer		2015 Summer	
	Number	Share	Number	Share
1	2	0.01	0	0.00
2	76	0.51	38	0.31
3	22	0.15	16	0.13
4	17	0.11	10	0.08
5	32	0.21	59	0.48
Total	149	1.00	123	1.00
Large refrigerators' share in label 5 (401 L~)	1.00		0.98	

Created based on data from Agency for Natural Resources and Energy [3]

Table 2 Refrigerator information for 159 households

Capacity (L)	Number			Energy consumption (kWh/year)					
				Total		5-star model			
	Total	5-star model	Best model	Mean	St. dev.	Mean	St. dev.	Max	Min
~ 140	2	0	0	163.00	82.00				
251–300	8	0	4	219.63	106.78				
301–350	21	0	7	285.00	132.49				
351–400	15	0	4	202.53	66.79				
401–450	44	34	0	252.25	135.58	232.94	24.20	280.00	190.00
451–500	24	24	4	201.04	75.97	220.00	27.23	270.00	180.00
501~	45	45	3	300.16	164.97	215.78	27.77	290.00	180.00
Total	159	103	22	254.95	136.47				

5-star models have not been available until recently

Calculation of yearly loss

The survey asked households to provide the model number of their refrigerator. We used a product catalogue to determine the capacity of each refrigerator and classified the 159 respondent households into seven classes according to their refrigerator's capacity. We also determined their refrigerator's the annual electricity use. The number of households in the seven capacity groups and share of households owning a 5-star model are presented in Table 2. The table shows that households having a large capacity model tend to purchase a 5-star refrigerator. Finally, we estimated the sales year for each refrigerator using the model number and identified the most efficient model available during each sales year. The table shows that only a small number of households purchased the most efficient model.

Table 3 Descriptive statistics of the 159 households

	Mean or share	Standard deviation
Yearly loss (JPY)	1445.83	1369.80
Socio economic characteristics		
Household size (number of persons in household)	3.01	0.97
Household income (1000JPY in 2014)	853.00	1011.70
Age (age of household head)	45.35	11.58
College dummy (If s/he went to a college = 1)	0.70	
Child dummy (If there is a child under 6 = 1)	0.37	
Pension dummy (If s/he receives pension benefit = 1)	0.14	
Dwellings characteristics		
Home owner dummy (If s/he is a home owner = 1)	0.69	
Detached house dummy (If the house is a detached house = 1)	0.38	
House size (m^2)	83.20	39.45
Construction year dummy[a]	4.47	1.29
Ownership of the energy-consuming durables		
Air conditioner (number of air conditioners)	2.55	1.38
Cloth dryer dummy (If s/he owns a dryer = 1)	0.51	
Dish washer dummy (If s/he owns a dishwasher = 1)	0.37	

[a]Here, we apply the notation of 1, 2, 3, 4, 5, and 6 for houses constructed before 1970, in the 1970s, in the 1980s, in the 1990s, in the 2000s, and after 2010, respectively

We calculate the yearly loss using the following four steps. First, we identified the annual electricity usage for each model from the product's catalogue. Second, we determined the annual electricity use of the most efficient refrigerator. Third, we subtracted the former's annual electricity usage from that of the latter to calculate the additional electricity required due to the selection of an inefficient model. Finally, by multiplying the additional electricity with the cost of electricity, we calculate the yearly loss.[1]

Table 2 shows that about 64.8% of households (= 103/159) owned a 5-star model. However, only 13.8% of households (= 22/159) owned the most efficient model. According to our calculation, a household that did not purchase the most efficient model pays an additional 1445.83 JPY for electricity per year on average (Table 3).

Descriptive statistics

The object of this study is to find the determinants of energy-efficiency investment in refrigerators. Following previous studies that analyzed household's energy-efficiency investment behavior, we include (1) socioeconomic characteristics of households, (2) characteristics of their residences, and (3) ownership of other home appliances. Socioeconomic characteristics of households include household size, income, age of

[1] The detailed derivation of the yearly loss is explained in the Appendix.

household head, attainment of a college-level education, presence of a child under 6 years old, and being a recipient of pension benefits.

Descriptive statistics of surveyed households are provided in Table 3. The average household income was approximately 8,530,000 JPY in 2014. Households with a higher income tend to purchase a larger refrigerator. In the survey, about 70% of households stated that they had attended college, and about 14% of households answered they are retirees. The average household in the survey had three members.

Table 3 also summarizes residence characteristics. Most households live in homes built in the 1990s or 2000s. About 62% of households lives in an apartment, and about 38% lives in a detached house. Approximately 69% of households are a homeowner, whereas 31% of them rent instead.

Finally, Table 3 presents ownership details for other energy-consuming durables. It shows that households owning a large refrigerator tend to live in a large detached house and own many appliances.

Empirical model and result

Empirical model

If a household purchases a less-efficient model, then it must pay the additional electricity cost in the future. Our interest is to identify the factors that induce such underinvestment behavior. In the following empirical analysis, we use the yearly loss to identify the determinants of this underinvestment.

Only 22 out of 159 respondents had purchased the most-efficient model. Although the yearly loss for those households becomes zero, the remaining households have a positive loss. Because the dependent variable of yearly loss is truncated at zero, the Tobit model is desirable.

We denote the degree of underinvestment by household i in income group g as y^*_{gi}. It is assumed that y^*_{gi} is determined by socioeconomic characteristics of households $\boldsymbol{X}_{gi}$, dwellings characteristics $\boldsymbol{Z}_{gi}$, and ownership of other home appliances $\boldsymbol{W}_{gi}$ as follows:

$$y^*_{gi} = \alpha + \mathbf{B}\boldsymbol{X}_{gi} + \boldsymbol{\Gamma}\boldsymbol{Z}_{gi} + \mathbf{H}\boldsymbol{W}_{gi} + \omega_{gi}$$

where α, $\mathbf{B}$, $\boldsymbol{\Gamma}$, and $\mathbf{H}$ are parameters to be estimated. We observe

$$y_{gi} = \begin{cases} 0 & if\ y^*_{gi} \le 0 \\ y^*_{gi} & if\ y^*_{gi} > 0 \end{cases}$$

where y_{gi} is the yearly loss for household i in income group g.

Although we include household income in $\boldsymbol{X}_{gi}$, we do not know precisely how household income affects that household's energy efficiency investment. To consider potential heterogeneity across different income classes, we assume that a residual term ω_{gi}, which can be described as follows:

$$\omega_{gi} = c_g + \varepsilon_{gi}$$

where c_g is an unobserved group specific effect and ε_{gi} is an idiosyncratic error.

Empirical results

Table 4 presents the results of the empirical analysis.[2] We observe a U-shaped relationship between age of household head and yearly loss, namely an individual will increase energy-efficiency investment until they become 43 years old, after which, this investment decreases. Although younger households cannot purchase expensive home appliances due to the budgetconstraint, older households hesitate to purchase expensive home appliances considering the usage period. This finding is consistent with the finding by [4]. We also find that a household whose head has attained a college-level education is more likely to purchase an energy-efficient refrigerator. This result is consistent with the finding of Ameli and Brandt [2].

Household income often plays an important role in residential energy use and conservation. In Table 4, the income variable is positive and statistically significant at the 10% level. This result suggests that wealthy households tend to purchase an inefficient refrigerator. It can also be seen that an increase in income leads to a larger energy-efficiency investment, such an increase also leads to a larger electricity usage [12]. A wealthy household would sacrifice one desirable feature (energy efficiency) to obtain another attractive feature, such as mega and rapid freeze or vacuum chilling capability.

The household size variable is positive and statistically significant at the 1% level. Thus, households with many members tend to purchase inefficient refrigerators. Since large households spend more money to purchase a large refrigerator, they may pay less attention to the benefit from energy efficiency investment. In addition, large households use more electricity than small households, i.e. higher electricity bill.[3] Thus, the savings from the purchase of an energy-efficient refrigerator would be small compared with their total electricity bill.

Davis [7] reports that home ownership is associated with a higher energy-efficiency investment in home appliances. We obtain similar empirical evidence to support his claim. We also find that a household living in a detached house tends to own an inefficient refrigerator. A household living in a detached house, in general, consumes more electricity than one living in an apartment [12]. Therefore, the former household has more options for reducing its electricity usage than the latter, thus, a household living in a detached house may engage in energy-conservation activities more aggressively [23]. However, we find that Japanese households living in a detached house do not intend to reduce electricity usage by purchasing energy-efficient refrigerators.

We also examine whether households living in older houses tend to own energy-inefficient refrigerators. The result shows that households living in older houses, built in the 1970s, own energy-inefficient refrigerators whereas households living in relatively newer houses, built in the 1980s, own energy-efficient refrigerators. Since households living in old houses spend a large amount of money for energy services, they would

[2] The AIC of the model with cluster standard errors (AIC = 2427.229) shows a better result than that of the model without robust standard errors (AIC = 2467.229).

[3] The marginal electricity cost of an additional household number is JPY 253.614 per year.

Table 4 Determinants of underinvestment: Tobit model estimation (N = 159)

Variable	Coefficient		Standard error
Socioeconomic characteristics			
Household size	253.614	***	76.905
Household income	0.123	*	0.065
Age	− 193.341	***	60.815
Age square	2.286	***	0.551
College dummy	− 395.588	**	196.312
Child dummy	− 334.337		224.409
Pension dummy	− 621.555		388.108
Residences characteristics			
Home owner dummy	− 589.670	***	135.996
Detached house dummy	210.634		156.755
House size	1.821		6.437
Construction year dummy (reference to 2010 ~)			
~ 1970	− 1.119		724.114
1970s	822.971	***	248.479
1980s	− 289.958	***	102.727
1990s	− 259.377		407.815
2000s	16.004		181.871
Appliance ownership			
Air Conditioner (reference to 6 units)			
1 unit	− 1673.364	***	443.173
2 units	− 985.604		600.491
3 units	− 1709.383	**	839.96
4 units	− 1791.92	*	1003.086
5 units	− 1540.597		1087.626
Cloth dryer dummy	164.572		303.560
Dishwasher dummy	− 471.567	***	132.230
Constant	6476.284	***	1549.748

***, **, and * indicate significance at 1, 5, and 10% level, respectively

consider that the impact of energy saving obtained through the purchase of an energy efficient refrigerator is relatively small. Finally, regarding home appliance ownership, we find that ownership of ACs and dishwashers is associated with the energy-efficiency investment of refrigerators. This result may indicate that households that purchase more home appliances, considers their performance in order to reduce the total amount of electricity consumed by the appliances they own.

Conclusion

Although many countries have introduced various energy-saving programs to promote energy-efficient appliances, the market penetration of energy-efficient appliances remains low. Households tend to not choose an energy-efficient model even if they are informed that they could fully recover its high upfront cost. This study surveyed refrigerator owners to identify the factors that affect household investment decisions regarding energy-efficient appliances. More specifically, we used the product model information and estimated the additional electricity cost caused by the purchase of less-efficient refrigerators. Based on this precise cost information, we identified the factors that affect the energy-efficiency investment decision of households.

We obtained empirical evidences that support the findings of previous studies. For instance, we found that middle-age homeowners tend to purchase an energy-efficient refrigerator. However, wealthy households with many family members are more likely to purchase an inefficient refrigerator. Given the fact that those households own larger refrigerators, policies to induce them to purchase energy-efficient appliances would be particularly effective in reducing energy usage by this type of appliance.

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Appendix: Calculation of yearly loss

All households in the survey purchased electricity from Tokyo Electric Power Company Holdings (TEPCO). Because TEPCO adopt a three–block pricing structure for residential electricity consumption, we estimate the electricity bill of each household in the following manner:

First block (< 120 kWh per month)

$$\text{Electricity bill} = \text{basic charge} + \text{electricity price in block } 1 \times \text{electricity usage}$$

Second block (121–300 kWh per month)

$$\text{Electricity bill} = \text{basic charge} + (\text{electricity price in block } 1 \times 120) + (\text{electricity price in block } 2 \times (\text{electricity usage} - 120))$$

Third block (> 300 kWh per month)

Electricity bill = basic charge + (electricity price in block 1×120) + (electricity price in block 2×180) + (electricity price in block $3 \times$ (electricity usage − 300))

The monthly electricity usage of the 159 households are presented in Fig. 1. Figure 1 shows that most households use 121–300 kWh per month.

Due to the block-pricing structure, different household may pay different electricity prices. Using total energy consumption information, we initially identify the block where each household is located. We then used the corresponding formula to calculate the average electricity price. For a precise calculation, we used the average electricity price for the year in which the refrigerator was purchased.

The additional electricity usage by an inefficient refrigerator is calculated by subtracting the electricity usage of the most efficient model released in the purchase year with the corresponding capacity from the electricity usage of the model owned. We then multiply the additional electricity usage by the average

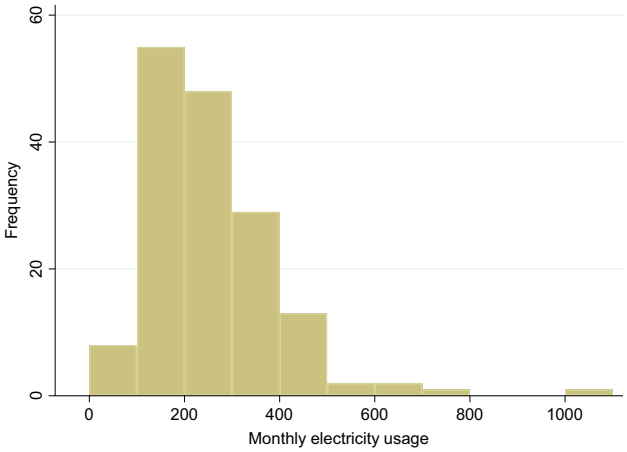

Fig. 1 Monthly electricity usage of households (kWh)

Table 5 Summary of yearly loss (N = 159)

Capacity(L)	Yearly loss (JPY)			
	Mean	Median	Max	St. Dev
~ 140	882.97	882.97	1529.64	914.53
251–300	1155.91	750.50	2841.30	1294.05
301–350	2565.11	3308.20	5103.40	2096.97
351–400	1901.69	2363.00	4534.20	1751.55
401–450	1835.74	1400.20	4786.10	1208.36
451–500	789.40	615.70	2037.00	659.21
501~	816.96	585.60	2077.90	577.43
Total	1445.83	1072.20	5103.40	1369.80

price to estimate the additional monthly cost incurred by the less-efficient model. Finally, by multiplying the additional monthly cost by 12 months, we obtained the yearly loss. The summary of estimated yearly losses is presented in Table 5

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