RIETI Discussion Paper Series 15-E-063

Consumer Valuations of Energy Efficiency Investments: The case of Vietnam's air conditioner market

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RIETI Discussion Paper Series 15-E-063
May 2015

Consumer Valuations of Energy Efficiency Investments: The case of Vietnam's air conditioner market[1]

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Abstract

Typical consumers underestimate the benefits of future energy savings and underinvest in energy efficiency relative to the socially optimal level of energy efficiency. This phenomenon is called the energy-efficiency gap and has been widely studied in many developed countries. However, research on the energy-efficiency gap in developing countries remains very scant. In this study, we use sales data of air conditioners (ACs) in the Vietnamese market and conduct hedonic price analysis to examine how consumers in Vietnam value the energy efficiency of ACs. We find that the implicit discount rate in Vietnam's AC market exceeds 11.7%. This high implicit discount rate suggests that consumers in developing countries place much lower value on energy efficiency than consumers in developed countries, despite the fact that purchasing energy-efficient appliances offers the opportunity to save substantial amounts. Financial and technical support from developed countries are necessary to promote energy-efficient appliances in developing countries.

Keywords: Air conditioner, Energy-efficiency gap, Hedonic price analysis, Implicit discount rate, Vietnam
JEL classification: D12, Q13, Q41, Q55

[1] This study is conducted as a part of the Project "A Study on Trade/FDI and the Environment/Energy" undertaken at Research Institute of Economy, Trade and Industry (RIETI)
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1. Introduction

According to the United States Energy Information Administration (2014a), energy use in non-OECD countries will grow by 2.2% per year from 2010 to 2040. Simultaneously, energy use in OECD countries is projected to grow by only 0.5%. As a result of their higher growth rate, non-OECD countries' proportion of total global energy use is expected to exceed 65% in 2040.

Although OECD countries still emit far more CO_2 than most other regions on a per capita basis (OECD, 2012), there are significant increases in per capita emissions from rapidly growing non-OECD economies. For instance, per capita CO_2 emissions in China increased from 2.7 metric tons in 2000 to 6.2 metric tons in 2010 while emissions in Vietnam increased from 0.7 metric tons to 1.7 metric tons over the same time frame (World Bank, 2014). These statistics reveal the importance of energy savings in developing countries.

As incomes rise, households in developing countries begin purchasing home electric appliances. For example, for every 100 urban Chinese households in 2000, there were 30.80 air conditioners (ACs), 49.10 water heaters, 9.70 computers, 17.60 microwave ovens, and 19.50 cellphones. By 2010, these numbers had risen to 112.07 ACs, 84.82 water heaters, 71.17 computers, 59.00 microwave ovens, and 188.86 cellphones (National Bureau of Statistics of China, 2013).

Farrell (1954) argued that an S-shaped relationship exists between household income and asset ownership; the ownership ratio of energy-using assets remains low until the per capita income reaches a certain “acquisition” threshold, but takes off very rapidly after that.

The World Bank (2008) examined the acquisition of refrigerators and ACs in India. It then estimated that the threshold for refrigerator ownership is just below an annual income of 10,000 USD per household, while that for an AC is just below 20,000 USD. Based on these estimations, Deutsche Gesellschaft für Internationale Zusammenarbeit (2013) predicted that the number of refrigerators in developing countries will grow from 0.6 billion to over 2.5 billion by 2050, while the number of ACs will grow from 0.5 billion to 1.5 billion over the same period. Similarly, Gertler and Wolfram (2011) examined the impact of Mexico’s conditional cash transfer program on the acquisition of refrigerators and confirmed the S-shaped relationship. Wolfram, Shelef, and Gertler (2012) analyzed the relationship between total annual expenditure per person in Mexico and the acquisition of refrigerators and cars and then estimated that the threshold value for each of these durables was around 800 USD.

Increased ownership of energy-using durables will be a major driver of energy demand in developing countries. Therefore, many researchers have extensively analyzed the diffusion process of appliances (McNeil and Letschert, 2005; de la Rue du Can et al., 2009; US Energy Information Administration, 2014b). Nevertheless, less attention has been paid to the energy efficiency of appliances sold in developing countries. Large variations exist in appliance energy efficiency around the world, and consequently appliance energy consumption during use varies substantially. Simply knowing how many appliances will be sold does not provide sufficient information to accurately forecast future energy demand in developing countries. Information on appliance type must also be known.

Accordingly, accurately estimating future energy use in developing countries requires data regarding the following questions. Do people in developing countries value energy efficiency similarly to people in developed countries? Do people in developing countries purchase appliances with similar energy-efficiency ratings as those bought in developed countries? How much can energy consumption and CO_2 emissions be reduced through the promotion of energy-efficient appliances? This study aims to answer these practical questions.

Typical consumers underestimate the benefits of future energy saving and underinvest in energy efficiency relative to the socially optimal level of energy efficiency.[1] This phenomenon was named the "energy-efficiency gap" by Jaffe and Stavins (1994) and has been widely studied in many developed countries (Train, 1985; Dubin, 1992; Sanstad, Hanemann and Auffhammer, 2006). In contrast, studies examining the energy-efficiency gap in developing countries are not readily available.

There are reasons to believe that people in developing countries form future expectations differently from people in developed countries. Meier and Whittier (1983) reported that valuations of energy efficiency vary across geographical regions within the United States. A country's geographical conditions are also likely to influence citizens' future expectations. Developing countries are growing more rapidly than developed countries. Therefore, the optimal social discount rate given by the Ramsey formula (Weitzman, 2007) in developing countries is larger than the one for developed countries. Differences in social discount rates will affect future expectations. Past

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[1] Since discounting plays a central role in the cost-benefit analysis of many public policies, individual discounting behavior has been studied outside of the context of energy efficiency investment also. For instance, Carson and Tran (2009) reviewed individual responses to common resource management and health risk. It is known that the similarity about discounting behavior among individuals is necessary for the success of common resource management. Discounting behavior determines the coverage of health insurance. In energy efficiency investment, people simply compare capital cost with operation cost. Thus, we can discuss individual discount behavior in monetary terms.

studies reported that low-income households displayed much higher implicit discount rates than high-income households (Goett, 1978; Hausman, 1979; Cole and Fuller, 1980; Goett and McFadden, 1982; Berkovec, Hausman and Rust, 1983; Goett, 1983; Arthur D. Little, Inc., 1984; Lawrance, 1991). Liquidity constraints mean that households in developing countries cannot afford an energy-efficient appliance even if they know that such a purchase would be beneficial to them in the long run. Finally, people in developing countries often lack information about differences in future operating costs between more efficient and less efficient products that would enable them to make proper investment decisions (Howarth and Sanstad, 1995).

The rest of the paper is organized as follows. In the next section, we conduct a brief literature survey of implicit discount rate. Section 3 provides background information about Vietnam's AC market. In Section 4, we explain our dataset, which contains data on ACs obtained from GfK Marketing Service. We employ a hedonic price model to show how Vietnamese consumers value energy efficiency in ACs. In Section 5, we specify our empirical model. In Section 6, we and report empirical findings. The empirical results demonstrate that Vietnamese consumers place a much lower value on energy efficiency investments than consumers in developing countries. Using the estimation results, we conduct several simulation analyses and calculate the benefit of energy saving in Section 7. We discuss policy implications and conclude in Section 8.

2. Literature Survey

The energy-efficiency gap is often illustrated through comparison with the market discount rate and the implicit discount rates that are implied by consumer choices concerning appliances with different costs and energy efficiencies (Hausman, 1979). Four types of empirical models have been used to measure implicit discount rates (Train, 1985; Dubin, 1992). In engineering models, prices for alternative technologies are compared to assess how changes in posted prices reflect alternative levels of stated efficiencies. In stated preference models, consumers' willingness to pay for improved energy efficiency is estimated from survey data. In choice models, individual choices regarding alternative energy-using durables are analyzed based on the discrete-choice framework. In hedonic models, prices of energy-using durables are regressed on their characteristics.

Table 1 summarizes the implicit discount rates that prior studies estimated for home energy-related products. Most research estimated the implicit discount rate to be higher than the standard social discount rate, 3% to 7% (Carson and Tran, 2009). However, discounts rates were found to differ across products classes and attributes of products (Winer, 1997). With respect to the region examined, most papers studied U.S. consumer valuations of energy efficiency investments.[2] No studies were conducted in developing countries. Most papers employed choice models.[3]

In light of the research methodologies used by previous studies, we decided to use a hedonic model to estimate the implicit discount rate in a developing country. Our reasoning for this choice of model is as follows. Although both choice and hedonic models describe the trade-off between appliance sales prices and energy efficiency, they may not estimate identical discount factors. Product energy efficiency is calculated under certain operating conditions. However, most households will not use their appliances under those specific conditions. Instead, households process energy efficiency information differently and derive their own subjective expectations about future energy savings. In a product choice situation, they compare future savings with the product price. Thus, the impact of energy efficiency information depends on how

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[2] Exceptions are Cohen, Glachant and Söderberg (2014) in the U.K. and Morita, Matsumoto and Tasaki (2015) in Japan.

[3] Hedonic models have been used to estimate the discount rate of other durables. For instance, hedonic models are used to estimate consumer valuation of fuel economy in Arguea, Hsiao and Taylor (1994), Espey and Nair (2005), McManus (2007), Fan and Rubin (2009), and Fifer and Bunn (2009).

households process energy efficiency information. In contrast, hedonic models directly evaluate the effect of the energy efficiency on the product price. A comparison between the findings obtained from hedonic and choice models is useful for improving our understanding of consumer valuations of energy efficiency investment.

3. Vietnam's AC market

The World Bank (2014) reported that the growth rate of Vietnam's Gross Domestic Product (GDP) increased from 5.4% in 2013 to 5.6% in 2014. This increase is attributed to the country's economic stability and the recovery of its manufacturing sector. These two factors are expected to have a positive impact on medium-term development as well.

In line with this economic growth, domestic electricity consumption in Vietnam has increased at an annual rate of 7% since 2000 (Vietnam Energy Report, 2015). Domestic electricity consumption is predicted to grow at an annual rate of 3.5%, rising from 55.6 Million ton of oil (Mtoe) in 2009 to 138.7 Mtoe in 2035 (Asia Pacific Economic Cooperation, 2013). The department of Climate Change and Energy Efficiency of Australian Government (DCCEE) predicted that the peak electricity demand in the residential sector will increase from 20GW in 2012 to 110GW in 2030

(DCCEE, 2014).

The DCCEE reported that about 22.5 million households in Vietnam were connected to the power grid as of 2012; 15.5 million of these were in rural areas and consumed an average 1,200 kWh per year while the 7 million in urban areas consumed an average of 2,700 kWh per year.

The diffusion of appliances is considered a major driver of increased electricity demand in the residential sector. According to a DCCEE survey of 1,830 Vietnam households, in 2012, ownership rates of several major appliances were as follows: televisions (90%), refrigerators (60%), personal computers (18%), and ACs (8%), respectively. On the other hand, the Japan External Trade Organization (JETRO, 2013a) conducted a survey of 400 households in Ho Chi Minh City and reported that ownership rates of televisions, refrigerators, personal computers, and ACs all exceeded 60% in 2012.

JETRO (2013b) reported that the AC ownership rate in urban areas increased from 8% in 2004 to 26.2% in 2010. Mitsubishi UFJ Morgan Stanley (2012) surveyed middle- and high-income households in Hanoi, Ho Chi Minh, and Da Nang and reported that 94% of households in Hanoi, 73% of households in Ho Chi Minh, and 55% of households in Da Nang owned ACs. These surveys suggest that an AC is becoming a necessary item among middle- and high-income households in Vietnam.

JETRO (2012) also conducted a survey of 250 households in Hanoi and surrounding villages; this confirmed the positive relationship between income and AC ownership. To place this finding in context, the DCCEE (2014) reports that people start purchasing an AC once their monthly household income reaches 6 million Vietnamese Dong (đồng) (281.63 USD).[4] The DCCEE's survey respondents replied that their household would purchase an AC only after purchasing a refrigerator and a washing machine. In JETRO's survey (2012), households indicated that purchasing a personal computer would take precedence over the purchase of an AC. Since current monthly household incomes are 2.99 million đồng (140.30 USD) in urban areas and 1.58 million đồng (74.11 USD) in rural areas (Vietnam Government, 2012), ACs are likely to become increasingly popular, particularly in urban areas.

The DCCEE (2014) further reports that space heating and cooling account for 17% of household electricity use, the second-largest use after lighting (19%). Considering future diffusion and the resultant impact on residential energy consumption, we believe that an analysis of its AC market is highly relevant for understanding trends in Vietnam's economy. We also believe that our analysis sheds light on the energy

[4] We assume that 1 đồng = 0.0000469373 USD throughout the paper.

problem in other developing countries.

4. Data

The primary data used in our analysis are sales data collected by the market research firm GfK Marketing Service Ltd, the fourth-largest market research firm in the world. GfK sales data include information on the number and value of AC sales on a single-model basis. GfK tracks actual sales data in a bottom-up manner.[5] It combines sales data collected from a representative sample of retail outlets with expert statistical analysis to construct overall sales data (GfK, 2015).

We use 2013 data in this study. AC sales in Vietnam are estimated to total approximately 750,000 while the total value of AC sales is estimated to be 6500 billion đồng (300.00 million USD). GfK data report the total number and sales value for each AC model. The dataset reveals that 37 manufacturers sold 1,001 varieties of ACs in Vietnam's market. The manufacturers have American, Australian, Chinese, Japanese, Indonesian, Korean, Malaysian, and Vietnamese origins.

Although product information is required for the hedonic analysis, product information from small manufacturers is often unavailable. Therefore, we decided to

[5] Top-down data like shipment data do not include the price paid at the store.

focus on the ACs produced by 13 major manufacturers. Although this reduces the number of AC models to 757, the number and value of sales of these models exceed 90% of total sales.

To examine the consumer valuation of energy efficiency investments, we need energy efficiency information on each model of AC examined in this study. Unfortunately, GfK data includes energy efficiency information only for a few varieties of ACs. We searched for the relevant energy efficiency information on manufacturer and retail store home pages, which enables us to obtain energy efficiency and other product information for 443 AC models.

5. Empirical Models

ACs designed for larger rooms require more electricity and are generally more expensive. To accurately measure consumer valuations of energy efficiency, we have to control for the size of the room in which it is the consumer's intention to use the AC unit. If this factor is not considered, the data could imply that higher energy-consuming ACs are more expensive.

Figure 1 presents a scatter diagram depicting ACs' maximum cooling capacity

(BTU) and sale prices (đồng).[6] A clear positive relationship is observed. However, the relationship becomes less clear as the BTU range is narrowed.

[Basic Model]

We first estimate the following log-linear hedonic model to evaluate consumer valuation of ACs' energy efficiency:

$$\ln p_m = \alpha + \beta_{BTU} BTU_m + \beta_{EER} EER_m + \boldsymbol{\Gamma X}_m + \varepsilon_m \tag{1}$$

where p_m is the price of the m^{th} AC, BTU_m is the maximum cooling capacity, EER_m is the energy efficiency ratio (explained below), and $\boldsymbol{X}_m$ is the vector of product characteristics whose descriptive statistics are presented in Table 2. After controlling for the intended room size with BTU, we examine consumer valuations of the energy efficiency investments with EER.

An AC's energy efficiency ratio is calculated by dividing its cooling capacity BTU_m by its applied electrical power, AEP_m:

$$EER_m = \frac{BTU_m}{AEP_m}. \tag{2}$$

A higher value of EER means that less energy is required to cool a certain space.

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[6] For an illustrative purpose, four observations where prices exceeded 55,000 VND have been removed from Figure 1.

In Equation 1, the parameter β_{BTU} measures the value of space cooling and the parameter β_{EER} measures the value of an energy efficiency investment. We expect positive signs on both parameters.

[Class-Specific Model]

The basic model specified by Equation 1 assumes that the value of an energy efficiency investment is the same for all room sizes. However, this assumption is unrealistic since the electricity saving from a unit increase in EER increases along with room size.

We classified ACs into five classes according to their *BTU* value as presented in Table 3. We then estimate the following class-specific model to account for the difference in the effect of EER across five class sizes:

$$\ln p_m = \alpha + \beta_{BTU} BTU_m + \boldsymbol{B}_{EER,c} \boldsymbol{I\_EER}_{m,c} + \boldsymbol{\Gamma X}_m + \varepsilon_m \quad (3)$$

where $\boldsymbol{I\_EER}_{m,c}$ is the vector of the interaction terms between class size dummies and energy efficiency ratios. Therefore, the parameters of $\boldsymbol{B}_{EER,c}$ estimate a class c's specific EER valuation.

To further analyze how the EER valuations differ across AC sizes, we use only class c's samples and estimate the following model:

$$\ln p_m = \alpha + \beta_{EER,c} EER_{m,c} + \boldsymbol{\Gamma X}_m + \varepsilon_m, \tag{4}$$

for each class. Since we focus on ACs designed for a specific room size, the control variable of *BTU* is removed from this specification.

6. Estimation Results

[Basic Model]

There are two inherent problems in our dataset. While the same AC is sold at a range of prices, individual sales data are not available. Therefore, we need to use the mean price in our empirical analysis. There is a large variation in the number of sales across AC models. We have to consider the representativeness of each AC model. Diewert (2003), Silver (2002), and Silver and Heravi (2005) argued that a weighted least squares (WLS) method should be employed to treat observations as representative in hedonic analyses. They further argued that the WLS with value weights is better than the one with quantity weights since quantity weights give too little weight to the expensive products and too much weight to the cheaper products. Considering their arguments, we estimate three versions of the basic model: OLS, WLS with the number of sales, and WLS with sales value.

The estimation results are presented in Table 4. The coefficient on BTU is positive and significant at the 1% level in all three models. This implies that an AC's price increases as its cooling capacity increases. The coefficient on EER is positive in all three models and becomes significant at the 1% level in the two WLS models. These results imply that Vietnamese households purchase energy-efficient ACs at higher prices.

The basic model includes several dummy variables concerning AC functions and characteristics. Using the estimation result of the WLS with sales value model, we estimate the impact of the change in AC functions and characteristics upon sales price in terms of percentage change by inserting the estimated coefficient γ into the following formula: $100(e^{\gamma} - 1)$. Table 5 demonstrates that AC sales prices increase by 21.89% if a heating function is installed. Similarly, sales prices increase by 12.55% if an anti-bacteria function is installed.

Compared to the price of Japanese-brand ACs, the sale prices of Korean- and Vietnamese-brand ACs are lower by 11.01% and 15.70%, respectively. In JETRO's (2012) survey, Vietnamese households stated that they placed a high value on product quality, brand image, product design, and manufacturer's country. The survey further reported that a typical consumer considers Japanese products to be high quality and thus has a high perception of Japanese brands. Our results provided additional empirical support for the survey result.

Most ACs sold in the Vietnamese market are manufactured in Thailand. Compared to the prices of ACs made in Thailand, the prices of ACs made in Vietnam and Malaysia are lower by 19.74% and 6.90%, respectively.

[Class-Specific Model]

The estimation results of the class-specific models specified by Equations 3 and 4 are presented in Table 6.[7] Although some variables become insignificant, most results remain unchanged from those of the basic model given in Table 5.

The coefficients on EER become positive and significant except for one case. The non-significance of EER in Class 5 is possibly due to the large variation in AC size. The results also show that a positive relationship would exist between the coefficients on EER and class size. As expected, the value placed on improvements in energy efficiency as evaluated by EER increases as AC size increases.

7. Simulation Analyses

7.1. Capital Cost

[7] We again use sales value as weights.

In Vietnam's AC market, Japanese manufacturers accounted for 75.73% of total sales by number of items and 80.70% by total sales value. Similarly, Japanese manufacturers account for the lion's share in Japan's AC market. Here we examine whether the ACs sold in these two countries have similar energy efficiency ratios. Figures 2a and 2b compare the distributions of EER of ACs in Vietnamese and Japanese markets. The Vietnamese data are from 2013 while the data for the Japanese market cover the period from April 2010 to October 2010. The figure clearly demonstrates that ACs in Vietnam's market have much lower EERs than ACs in the Japanese market.[8]

Next, we consider the hypothetical situation in which the average EER of ACs in Vietnam's market rises to match that of ACs in the Japanese market. Table 7 presents the capital cost required to improve Vietnamese $EERs$, Δp. For instance, the average EER of a Class 1 AC in the Vietnam market is 9.98. If this EER is improved to 15.97 (the average EER in the Japanese market), then the sales price is expected to increase by 602,419 đồng (about 28.28 USD), an increase of 7.76%. Similarly, the rates of price increases obtained through energy efficiency improvements in Classes 2, 3, 4 and 5 are

[8] Due to the weather and housing conditions, manufacturers sells different types of ACs in different countries. For instance, the majority of ACs sold in the Japanese market have a heating function while a heating function is less common among Vietnamese AC models.

9.54%, 14.48%, 18.33%, and 15.05%, respectively.

7.2. Payback Period and Implicit Discount Rate

The hedonic analysis shows the effect of improved energy efficiency upon the AC price. To further analyze consumer valuation of energy efficiency investments, we impose additional assumptions on the usage of ACs.

Vietnam's climate varies across regions. Ho Chi Minh is hot and humid all year round and the annual average temperature exceeds 27 degrees Celsius. Hanoi's weather is hot and humid in the summer season but is cold and dry in the winter season. Therefore, we expect that AC use will vary substantially across geographical regions.

The DCCEE (2014) conducted a survey about lighting and appliance use in Vietnamese households in 2012. The survey reported that on average, households use their AC for approximately 4.3 hours a day. In contrast, Mitsubishi UFJ Morgan Stanley (2012) reported that ACs are used for an average of 12 hours per day.[9] Hence, there is a substantial difference between the two surveys. To keep simulation analyses conservative, we assume that an average household uses the AC for 4.3 hours per day,

[9] It also reported that over 50% of people in Hanoi use the AC between 1 and 3 days per week while over 90% of people in Ho Chi Minh use it between 4 and 7 days per week.

120 days per year.

Vietnam Electricity (EVN) is the largest power company in Vietnam and uses non-linear electricity pricing for residential customers. The unit price of residential electricity increases with usage. Residential electricity prices in August 2013 were 993 đồng/kWh (<50kWh, low-income household), 1,418 đồng/kWh (0–100kWh), 1,622 đồng/kWh (101–150kWh), 2,044 đồng/kWh (151–200kWh), 2,210 đồng/kWh (201–300kWh), 2,361 đồng/kWh (301–400kWh) and 2,420 đồng/kWh (beyond 400). In this study, we use the median price of 2,044 đồng/kWh (100–150kWh). We assume that this electricity price remains the same for 10 years of product use.

Under these assumptions, we use applied electrical power (AEP) of AC from Equation 2 to calculate annual electricity consumption:

$$ELE(\text{kWh}) = AFP(\text{wh}) \times \frac{1}{1000}(\text{kWh/wh}) \times 4.2(\text{h}) \times 120(\text{days}).$$

We subtract the AC's annual electricity consumption with the Japanese EER from that with Vietnam's EER and then estimate the annual electricity savings, ΔELE. By multiplying ΔELE by the electricity price, we can calculate the annual electricity cost saving, ΔC_{ELE},

$$\Delta C_{ELE}(\text{đồng}) = \Delta ELE(\text{kWh}) \times 2044(\text{đồng/kWh}).$$

The results are presented in Table 7.

Finally, we divide the capital cost to improve EER by the annual electricity cost savings to calculate the payback period:

$$Payback\ Period \text{ (Year)} = \frac{\Delta p(\text{đồng})}{\Delta C_{ELE}(\text{đồng})}.$$

Table 7 shows that the payback periods are 1.63 years for Class 1 ACs, 1.96 years for Class 2 ACs, 3.41 years for Class 3 ACs, 5.17 years for Class 4 ACs, and 3.98 years for Class 5 ACs. These short payback periods suggest that Vietnamese households do not invest sufficiently in energy-efficient ACs.

Using the price increase and annual energy saving thorough EER improvements, we can calculate the implicit discount rate θ that meets the following equality:

$$\Delta p = \sum_{t=0}^{9} \left(\frac{1}{1+\theta/100}\right)^{t} \Delta C_{ELE}.$$

The estimated implicit discount rates presented in Table 8 range from 11.7% to 312.0%. These implicit discount rates are larger than the ones reported in previous papers such as Hausman (1979), Goett (1983), and Morita, Matsumoto and Tasaki (2014). Since we impose conservative assumptions on AC usage, the actual discount rates would be even larger than the current estimations. The high implicit discount rates imply that Vietnamese consumers place much lower value on AC's energy efficiency than consumers in developed countries.

Table 8 also shows that the implicit discount rate of small ACs is higher than that of large ACs. Thus, people purchasing a small AC invest less money in energy-saving features compared to people purchasing a large AC. This difference probably reflects the liquidity constraints of people purchasing a small AC.

7.3. Cost of CO_2 Reduction

According to the International Energy Agency (2013), CO_2 emissions per kWh from electricity generation in Vietnam were 0.429 kg in 2011. Multiplying this figure by the estimated annual electricity saving through the purchasing of an energy efficient AC, we calculate an expected CO_2 reduction. Finally, by dividing the expected CO_2 reduction by the capital cost to obtain an energy-efficient AC allows us to estimate the per-unit cost of CO_2 reduction:

$$C_{CO2}(\text{đồng/ton}) = \frac{\Delta p(\text{đồng})}{\frac{1}{1000}\times 0.429(\text{kg/kWh})\times \Delta ELE(\text{kWh})}.$$

The unit costs presented in Table 7 range from 777,445.61 đồng/ton (36.49 USD/ton) to 2,464,787.56 đồng/ton (115.69USD/ton). Although these values are larger than the social cost of global warming reported in the survey literature of Tol (2012), which was $29/ton, they are smaller than the cost of CO_2 reduction measures (around 200USD/ton) implemented in Japan (Matsumoto, 2015).

8. Discussion and Conclusion

Electrical appliances are vital to improving household living conditions in developing countries. As incomes rise in developing countries, more and more people are expected to purchase appliances in the near future. Simultaneously, increased electricity use to power these appliances has the potential to greatly increase CO_2 emissions and hence contribute to global climate change. Accordingly, the promotion of energy-efficient appliances in developing countries is necessary for the reduction of energy consumption and carbon emissions.

In this paper, we analyzed the sales data of ACs in Vietnam's market and found that ACs sold in Vietnam have much lower energy efficiency than those sold in the Japanese market. In the empirical section, we applied a hedonic model to the sales data of ACs to examine how Vietnamese households value making an energy efficiency investment. The analysis revealed that Vietnamese households apply a much higher discount rate than the rates found in previous studies, though these studies were conducted in countries other than Vietnam. These results suggest that although energy efficiency investments have great potential in developing countries,[10] getting people in

[10] Mitsubishi UFJ Morgan Stanley (2012) estimated that 121,853 tons of CO_2 emissions could be eliminated per year by introducing energy-efficient ACs into the Vietnamese market.

developing countries to make these energy-saving investments is more challenging than in developed countries.

Although this paper shows that people underestimate the benefit of energy efficiency investment, it does not explain the underlying mechanism due to data constraints. Our market data do not include the type of the buyers, which means, for example, that income constraints cannot be ruled out as a factor influencing type of AC purchased, rather than a lack of concern for energy efficiency. Household purchase data are required to pinpoint the precise reason for the model's underestimation.

Even without this additional analysis, several policies can be implemented to address the energy-efficiency gap. First, households in developing countries cannot easily access energy efficiency information. Therefore, they may purchase durables without understanding how much energy is required to run them. To improve access to energy efficiency information, more and more countries have begun to implement energy efficiency labeling programs. The Vietnamese government introduced a labeling program for several energy-consuming durables in January 2013 (Vietnam Certification Center, 2014). Since then, producers and importers have been obliged to show a product's energy efficiency on its label. The expansion of the labeling program to other energy-consuming durables and the introduction of labeling programs in other developing countries are required. However, many institutional barriers remain to implement labeling programs in developing countries (BRESL, 2013). Financial and technical support from developing countries is necessary for the labeling programs to be accelerated.

If households cannot rationally assess the benefit of future energy savings, incentive policies to induce households to purchase energy-efficient appliances are necessary. Although the textbook answer to this dilemma is to impose a tax, in real life, subsidy programs are rather more necessary in developing countries since households in developing countries tend to face severe liquidity constraints. Given these financial constraints, financial support from developed countries will be beneficial to support energy-efficient modes of development.

Together with policies promoting energy-efficient appliances, policies to remove energy-inefficient appliances from the market are also required. Implementation of a minimum efficiency standard, which should be updated periodically, would enable energy-inefficient appliances to be actively removed from the market. Considering the results of this paper, the amount of energy saving obtained from such dynamic incentive programs would be substantial.

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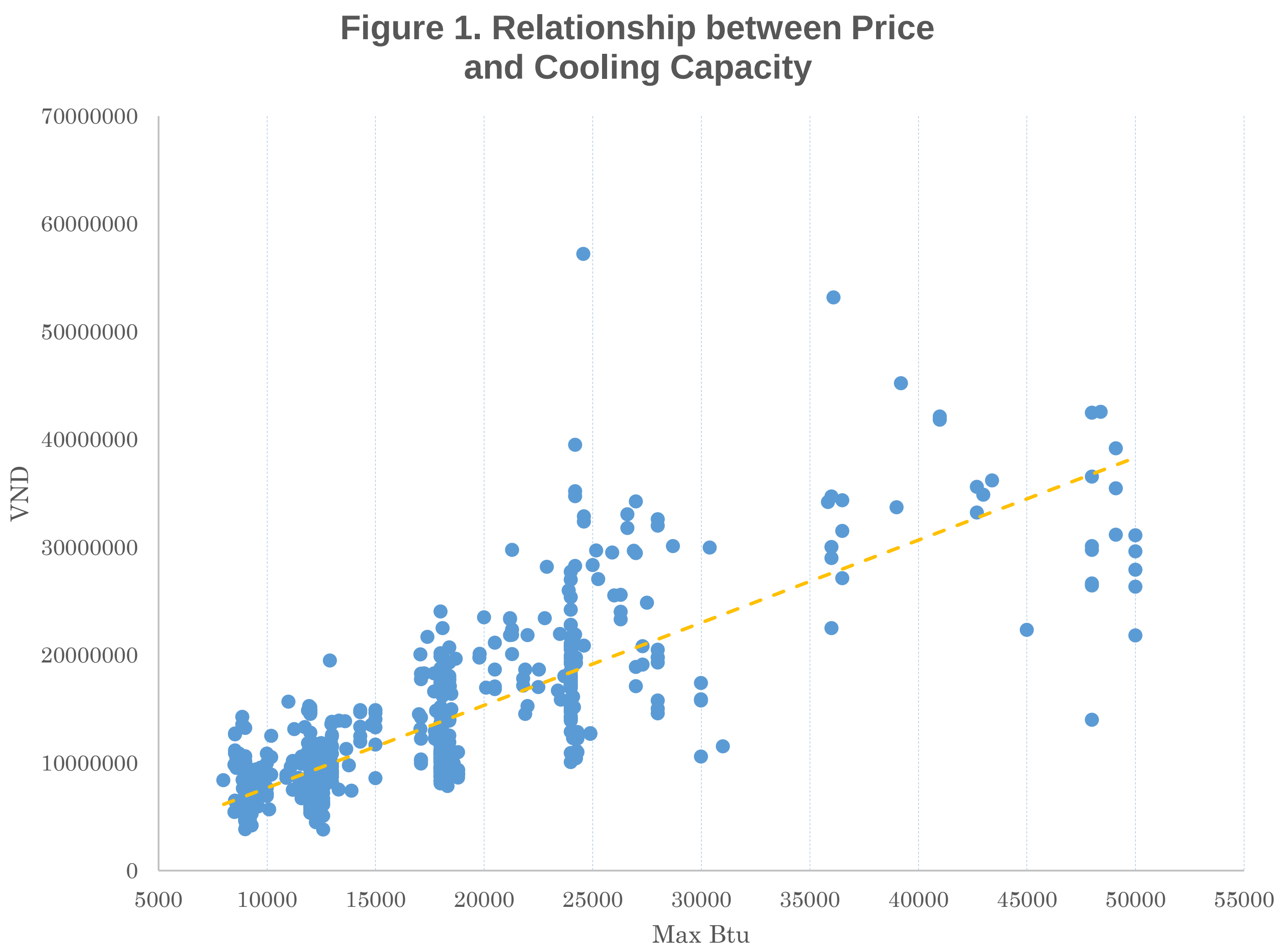
Figure 1. Relationship between Price and Cooling Capacity
70000000
60000000
50000000
40000000
30000000
20000000
10000000
0
VND
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
55000
Max Btu

Figure 2a. EER in Vietnam Market (2013)

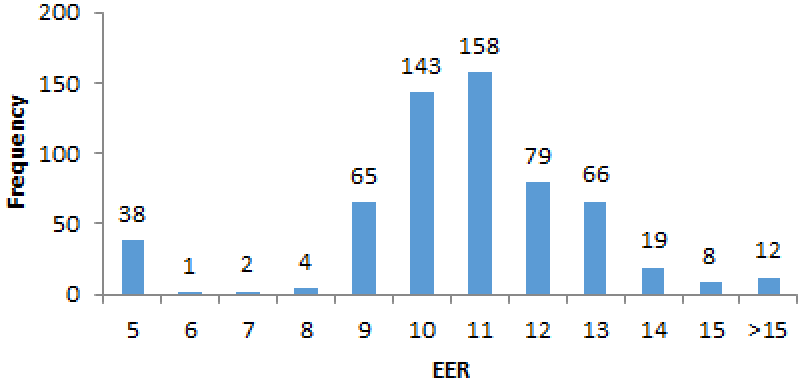

Figure 2b. EER in Japanese Market (2010.4-2010.9)

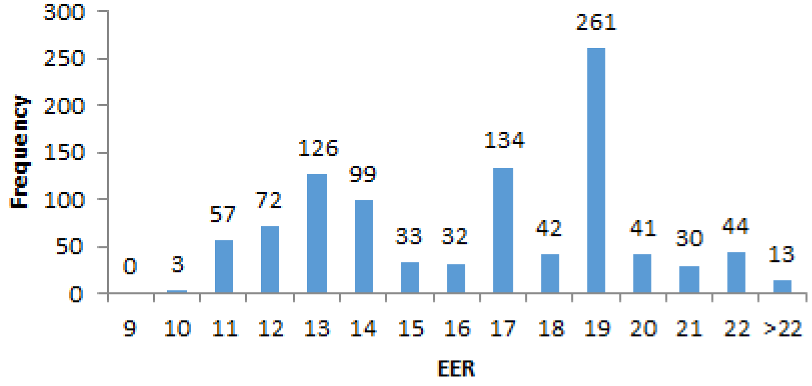

Table 1. Implicit Discount Rates of Household Products

Study	End-use products	Average Rate	Models
Cole and Fuller (national survey, 1980)	Thermal shell measures	26%	Choice Model
Arthur D. Little (1984)	Thermal shell measures	32%	Choice Model
	Window and door measures	10%	Choice Model
Corum and O'Neal (1982)	Thermal integrity of new homes (Gas-heated houses)	10%	Engineering Approach
	(Oil-heated houses)	14%	Engineering Approach
	(Electricity-heated houses)	19-21%	Engineering Approach
Goett (1978)	Space heating system and fuel type	36%	Choice Model
Berkovec, Hausman, and Rust (1983)	Space heating system and fuel type	25%	Choice Model
Goett (1983)	Space heating system and fuel type with central AC	4.4%	Choice Model
	without central AC	25%	Choice Model
Dubin (1985)	Space heating system and fuel type	2-10%	Choice Model
Dubin (1986)	Space heating system and fuel type	6.5-10.5%	Choice Model
Goett and McFadden (1982)	Space heating system and fuel type	6.5-16%	Choice Model
Cambridge Systematics, Inc. et al. (1988)	Furnace replacement	67.6%	Choice Model
Hausman (1979)	Air conditioning	29%	Choice Model
Goett (1983)	Air conditioning	3.2%	Choice Model
Morita, Matsumoto, and Tasaki (2014)	Air conditioning	2-18%	Hedonic Model
Cole and Fuller (1980)	Refrigerators	61-108%	?
Gately (1980)	Refrigerators	45-300%	Engineering Approach
Meier and Whittier (1983)	Refrigerators	34-58%	Engineering Approach
Revelt and Train (1998)	Refrigerators	39-46%	Choice Model
Cohen, Glachant, and Söderberg (2015)	Refrigerators	10.5%	Choice Model

Table 1. Continued

Study	End-use products	Average Rate	Models
Goett (1983)	Cooing and water heating fuel type	36%	Choice Model
Goett and McFadden (1982)	Water heating fuel type	67%	Choice Model
Berkovec, Hausman, and Rust (1983)	Water heating fuel type	33%	Choice Model
Dubin (1985)	Water heating fuel type	24%	Choice Model
Lin, Hirst, and Cohn (1976)	Cooking fuel type	7.0-31%	Choice Model

Table 2. Descriptive statistics of ACs (N = 433)

Variable	Definition	Unit	Mean or share	Standard Deviation
PRICE	Mean sales price	VND	10,993,500	6,766,438
BTU	Cooling capacity	BTU	15,632.67	8,331.54
EER	Energy efficiency ratio	Unit	9.98	2.80
Product characteristics				
OLD	Time after the initial sales date	Years	3.98	1.65
WARRANTY	Length of warranty	Months	15.67	5.91
SIZE	Physical size	1,000 cm^3	73.43	68.28
HEAT	Heating system	Dummy	0.22	
ANTIBACT	Anti-bacterial filter	Dummy	0.44	
DEODORAN	A deodorant feature	Dummy	0.61	
DEHUMID	Dehumidification mode	Dummy	0.67	
KOREA	Korean manufacture	Dummy	0.25	
VIETNAM	Vietnam manufacture	Dummy	0.21	
P_VIET	Made in Vietnam	Dummy	0.44	
P_MAL	Made in Malaysia	Dummy	0.09	

Note 1. The share is calculated by dividing the number of corresponding models by the total number of models (433#0).

Table 3. Classes of Room Air Conditioners

Class Size	Btu	Observations	Number of Samples
1	~10,900	242	136
2	10,901~14,999	197	134
3	15,000~19,999	149	79
4	20,000~24,000	73	39
5	24,001~	96	71
Total		757	433

Table 4. Estimation results for the basic model

	OLS			WLS (Weight = Number)			WLS (Weight = Value)		
	Coefficient		Standard Error	Coefficient		Standard Error	Coefficient		Standard Error
Constant	15.480	***	0.059	15.207	***	0.046	15.268	***	0.048
BTU	4.416E−05	***	1.905E−06	6.003E−05	***	2.639E−06	5.350E−05	***	2.226E−06
EER	0.008	*	0.004	0.013	***	0.003	0.014	***	0.003
OLD	−0.018	***	0.007	−0.011	*	0.006	−0.010		0.007
WARRANTY	−0.005	**	0.002	−0.004	**	0.002	−0.003		0.002
SIZE	0.001	**	0.000	0.000		0.000	0.000		0.000
HEAT	0.126	***	0.027	0.179	***	0.024	0.198	***	0.024
ANTIBACT	0.078	***	0.027	0.099	***	0.020	0.118	***	0.023
DEODORAN	−0.008		0.031	0.048	**	0.024	0.041		0.027
DEHUMID	0.041		0.038	−0.037		0.026	−0.033		0.030
KOREA	−0.026		0.029	−0.114	***	0.021	−0.117	***	0.023
VIETNAM	−0.056		0.036	−0.163	***	0.033	−0.171	***	0.040
P_VIET	−0.286	***	0.032	−0.204	***	0.022	−0.220	***	0.025
P_MAL	−0.011		0.046	−0.056	**	0.022	−0.071	***	0.023
Adjusted R^2	0.782			0.768			0.783		

Note. *, ** and *** indicate significant difference from zero at the 10%, 5%, and 1% level.

Table 5. Expected price change by feature attachment

Variable	Definition	%
Product characteristics dummies		
HEAT	Heating system	21.89
ANTIBACT	Anti-bacterial filter	12.55
DEODORAN	A deodorant feature	4.20
DEHUMID	Dehumidification mode	−3.22
Manufacture country dummies (Base country = Japan)		
KOREA	Korean manufacture	−11.01
VIETNAM	Vietnam manufacture	−15.70
Production origin dummies (Base country = Thai)		
P_VIET	Made in Vietnam	−19.74
P_MAL	Made in Malaysia	−6.90

Table 6. Estimation result for class-specific models

	Full sample model		Class 1 model		Class 2 model		Class 3 model		Class 4 model		Class 5 model	
Num. of Samples	433		136		134		79		39		71	
Constant	15.321	***	15.652	***	15.807	***	16.383	***	16.261	***	16.489	***
	0.059		0.091		0.153		0.139		0.269		0.197	
OLD	-0.011	*	-0.001		-0.018		-0.026	**	0.007		-0.022	
	0.006		0.010		0.011		0.011		0.021		0.022	
BTU	4.359E-05	***										
	4.155E-06											
C1_EER	0.013	***	0.011	*								
	0.003		0.005									
C2_EER	0.017	**			0.023	***						
	0.004				0.007							
C3_EER	0.028	***					0.018	**				
	0.005						0.009					
C4_EER	0.036	***							0.044	**		
	0.008								0.017			
C5_EER	0.012										0.030	**
	0.009										0.012	
WARRANTY	-0.003	*	-0.007	*	-0.003		-0.006	*	-0.015	***	-0.013	**
	0.002		0.004		0.003		0.003		0.005		0.006	

Table 6. Continued

	Full sample model		Class 1 model		Class 2 model		Class 3 model		Class 4 model		Class 5 model	
SIZE	0.001		0.002		0.002		-0.001		0.002		0.002	***
	0.000		0.001		0.002		0.001		0.001		0.000	
HEAT	0.188	***	0.204	***	0.176	***	0.210	***	0.119	**	0.040	
	0.023		0.051		0.038		0.031		0.048		0.062	
ANTIBACT	0.118	***	0.086	**	0.099	**	0.126	**	0.022		-0.094	
	0.022		0.034		0.042		0.054		0.075		0.092	
DEODORAN	0.052	*	0.124	***	0.027		-0.058		-0.071		0.246	***
	0.027		0.041		0.049		0.072		0.138		0.086	
DEHUMID	-0.038		0.016		-0.078		0.090		0.015		0.183	
	0.029		0.050		0.049		0.080		0.158		0.126	
KOREA	-0.117	***	-0.093	**	-0.156	***	-0.081	*	0.051		0.096	
	0.023		0.037		0.043		0.041		0.074		0.086	
VIETNAM	-0.160	***	-0.078		-0.224	***	-0.099		0.022		-0.040	
	0.039		0.062		0.080		0.062		0.180		0.110	
P_VIET	-0.217	***	-0.292	***	-0.111	**	-0.324	***	-0.145		-0.492	***
	0.025		0.044		0.046		0.056		0.089		0.115	
P_MAL	-0.078	***	-0.195	***	-0.057		-0.143	***	0.129	*	-0.283	***
	0.023		0.040		0.039		0.042		0.071		0.080	
Adjusted R^2	0.804		0.575		0.451		0.787		0.534		0.613	

Note. *, ** and *** indicate significant difference from zero at the 10%, 5%, and 1% level.

Table 7. Estimated impacts of energy efficiency improvements

	Average			Price				Annual Electricity Cost Saving	Payback Period	Annual CO_2 Saving[2]	Cost of CO_2 Reduction
	Vietnam	Japan	Unit[1]	Actual $\bar{p}_{EER=Vietna}$	Estimated $\hat{p}_{EER=Japan}$	Increase Δp	(%)	Estimated ΔC_{ELE}	(Years) $\Delta p/\Delta C_{ELE}$	(kg) ΔE	(per ton) $\Delta p/\Delta E$
Class 1	9.98	15.97	đồng	7,163,633	7,766,052	602,419	7.76	369,192	1.63	77.49	777,445.61
			USD	(336.24)	(364.52)	(28.28)		(17.33)			(36.49)
Class 2	10.15	15.97	đồng	8,680,358	9,595,341	914,983	9.54	467,418	1.96	98.10	932,677.14
			USD	(407.43)	(450.38)	(42.95)		(21.94)			(43.78)
Class 3	10.36	15.97	đồng	12,962,071	15,156,938	2,194,867	14.48	643,160	3.41	134.99	1,625,970.05
			USD	(608.40)	(711.43)	(103.02)		(30.19)			(76.32)
Class 4	10.41	15.97	đồng	18,820,950	23,045,155	4,224,205	18.33	816,562	5.17	171.38	2,464,787.56
			USD	(883.40)	(1081.68)	(198.27)		(38.33)			(115.69)
Class 5	10.53	15.97	đồng	26,999,689	31,781,818	4,782,129	15.05	1,200,085	3.98	251.88	1,898,596.61
			USD	(1267.29)	(1491.75)	(224.46)		(56.33)			(89.11)

Note: 1. đồng = 0.0000469373 USD

2. Based on IEA (2011), we assume that 0.466848028 kg of CO_2 is emitted to generate 1kWh of electricity.

Table 8. Implicit Discount Rate （%）

	Full model (Equation 3)	Sub sample model (Equation 4)
Class 1	158.3	312.0
Class 2	104.2	59.3
Class 3	39.4	87.3
Class 4	18.9	11.7
Class 5	193.6	30.4