Cost of conserved energy for residential energy appliances in Australia, Japan and Korea

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ABSTRACT

Improving energy efficiency is an important way to reduce energy consumptions and carbon emissions. With strong national energy efficiency programs, the efficiency of electric appliances available on the market can be improved significantly. The goals of this study are to determine the optimal efficiency targets for consumers in terms of net financial impacts and to quantify social and environmental benefits from efficiency improvement. To generate the relationship between efficiency and price and calculate the cost of conserved energy (CCE), I collected retail price, unit energy consumption (UEC) and efficiency level data from retail websites and government appliance registry websites. I then determined the relationship between price and efficiency using multivariable regression analysis. Three countries with independent energy labeling programs are considered in this study: Australia, Japan, and Korea. This analysis shows that high efficiency appliances are generally cost-effective for consumers and implies that potential improvements for higher efficiency levels exist. With the market rapidly adopting improved technologies and stronger enforcement of efficiency policies, the overall efficiency level of appliances will likely increase in the near future at a lower cost. The importance of the regression analysis of cost versus efficiency relationship is that it can be extended to imply further improvement opportunities beyond current markets.

KEYWORDS

Energy Efficiency Standard and Labeling, cost-benefit evaluation, energy efficiency, social benefits, international energy studies

INTRODUCTION

Climate change has been an global challenge for decades. Anthropogenic global warming threatens the well-being of living organisms on the Earth. A study estimated that the economic damage from climate change in California alone is between 7.4 and 46.6 billion US dollars (Roland-Holst and Kahrl, 2008). Growth in population, increasing demand from appliances for building services and comfort levels drive an upward trend in residential energy consumption (McNeil, 2011), which constitutes 25% to 30% of the total energy consumption worldwide (DOE/EIA, 2009). Improving energy efficiency at a relatively low cost, such as establishing energy efficiency programs, is an important way for us today to save energy and reduce emissions.

Government energy efficiency programs are essential to improve the efficiency of appliances (Tojo, 2005. E3 2010). Many governments around the world create mandatory standards for energy appliances in order to improve the overall efficiency level in the society. For example, Australia applied its energy labeling program, the Star Rating Scheme, as early as in 1986 (Harrington and Damnics, 2004). In 1992, Korea started making its own energy labeling program, Energy Efficiency Rating Labeling Program. Over time, growing number of appliances were introduced to the program with increasingly stringent standards (Harrington and Damnics, 2004). In 1999, the Japanese government began to implement the Top Runner program. This program requires manufacturers to improve their market weighted average energy efficiency level. Many studies found out that these appliances standards are effective to improve energy efficiency for appliances in different countries. For instance, a Wilkenfed and Associates (2009) estimate that over the period of 2000-2020, the Australian Efficiency Rating Labeling Program will save nearly 22,000 GWh per annum in residential sector and avoid emission 207.3 Mt of carbon. Some researchers assert that the Top Runner Program is the most effective national climate change policy in Japan, and without the Top Runner program, improvements in energy efficiency would never have gone this far" (Sugiyama and Takeuchi, 2008; Tojo, 2005). A study showed that the rates of energy efficiency improvements required by the Top Runner Standards range from 16% to 80%, which implies that the Top Runner Standards successfully improve the energy efficiency in Japan (Kimura, 2010).

Due to the effectiveness appliances standards, an increasing number of countries are implementing their own Energy Efficiency Standard and Labeling (EES&L) programs. Between 1990 and 2005, the number of EES&L programs worldwide has increased from 15 to over 60 (Wiel and McMahon, 2005). Through the creation of a mandatory standard for manufactures to produce more efficient electric appliances, EES&L is pushing the market to have more energy efficient appliances to save energy consumption for the society as a whole.

In addition to the benefits from energy consumption reduction, EES&L also has social and financial benefits for consumers. In today's market, competition between electronic devices has become increasingly rigorous as newer technologies are developed at a faster rate and cheaper prices. With the energy label sticker on the appliance, consumers will have opportunities to compare the energy efficiency of appliances when making purchasing decisions (Mahlia, et al, 2001). By purchasing a more efficient appliance, one can save money from electricity bills throughout its lifetime; and the nation saves energy bills as a result of individual savings from efficient appliances. A study in the U.S. shows that through 2030, the financial savings from electricity to U.S. consumers could potentially reach to USD$300 billion by investing in energy efficient equipment (McNeil et al, 2010). In China and India, the cumulative financial savings resulting from appliances standards through 2030 are estimated to be 686 billion USD and 58 billion USD, respectively (McNeil et al, 2011). By quantifying these economic benefits and energy savings, researchers can provide guidance for both policy makers as well as consumers on the effectiveness of energy labeling programs. However, the economic benefits for consumers from labeling and efficiency standards of Australia, Japan, and Korea, which have one of the most stringent energy standards in the world, remain unknown. It is important to evaluate these benefits to consumers for future policy decisions.

My objectives of this study are to determine the relationship between retail price and efficiency of the electric appliances in three different countries with independent energy labeling programs: Australia's Star Rating Scheme, Japan's Top Runner program, and Korea's Energy Efficiency Rating Labeling Program. I also aim to determine the efficiency targets for consumers in terms of positive net financial impacts. More specifically, I aim to investigate if consumers reap financial benefits from saving electricity bills, through investing in more efficient electric appliance and if there is economic potential in the market for future efficiency improvement.

METHODS

Overview of methodology

I generated the cost curves and the CCE curves for different electronic appliances in three countries, Australia, Japan and Korea, all of which have systematic energy efficiency labeling programs that regulate the energy performance of home appliances. Cost curve is the relationship between equipment efficiency and purchase price; it shows the price of one appliance at certain capacity level. The CCE curve is used to present the levelized cost of conserving energy over the lifetime of the appliance. The CCE is calculated through the incremental price, which is defined as the difference of price of an appliance between baseline and higher efficiency (Wiess el al, 2010). Cost-effectiveness is achieved when the consumer saves more electricity than they pay for the capital cost for the appliance per kWh (McNeil, el at. 2011). To generate those curves for residential appliances, I created my own database of retail price, annual energy consumption, capacity and efficiency labeling level. I collected price data through online electronic retail stores (see data source section). Other information of the appliance, such as energy consumption and capacity is from government energy labeling documents and registry websites (Energy Efficient Strategies 2010, Ministry of Economy, Trade and Industry 2010, Korea Energy Labeling).

Appliances included in the study

Because of data availability and cultural differences, I included different products for different countries. Table 1 shows a list of appliances in this study of each country.

Table 1. Appliance included in the study by different countries

Appliances	Australia	Japan	Korea
Air Conditioners	×	×	×
Washing Machine	×	×	×
Cloth Dryers	×		
Refrigerators	×	×	×
Rice Cookers		×	×
Gas boilers			×
Televisions	×	×	
Freezers	×	×	
Dish Washer	×		
Gas Water heater		×	
Oil water Heater		×	

Data Characteristics and Collection

Retail Price

Retail price is the major element in cost analysis and it is very important to this study. I collect the majority of price data through online retail stores (see appendix data source) of home appliances.

Unit Energy Consumption (UEC)

Unit Energy Consumption (UEC) is an indicator of how much energy an appliance consumes in one year and is expressed in kWh/year. Either the manufacturer or the government testing department measures the UEC with some assumption as to the hourly usage of the appliance. The source of UEC data is from governmental energy appliances standard documents (EES, 2010; METI, 2010. MKE 2010)

Capacity

The Capacity is the measurement of how big, or how powerful the appliance is. The capacity of an appliance is measured in terms of Liters (L), watts (W) or kilogram (kg). For example, the capacity of a refrigerator is the volume in the unit of liters; the capacity of a washing machine or a dryer is equal to the maximum weight, in kg, of clothing it can load per washing/drying cycle. Capacity is a very important factor influencing the price of the appliance. Generally speaking, devices with larger capacities tend to be both more expensive and consume more energy per year.

Electricity Tariff

The electricity tariff is the price of electricity paid by the consumers, and is used to evaluate the cost-benefit impacts to consumers for this study. I use the default electricity price for each country from each governmental appliances registry website.

Discount Rates and Lifetime

I collected default discount rates, which discount the value of money in the future, and lifetime of the appliance, which is the period of time on average an appliance is in use, assumptions for each country through registry websites. I need discount rate to calculate the future value of money and the levalized cost.

Data Analysis

Cost Analysis

To establish the efficiency vs. cost analysis, I made two assumptions. First, I assumed that the price of the appliance is mainly driven by efficiency and capacity, especially under the influence of the energy labeling program. The second assumption was that the price of the appliance increases as a power law with capacity and efficiency. This implies that the price increases faster with bigger and more efficient appliances, because of the increased amount of material the manufacturer must put into the production of the product.

The Cost Curve

To generate the cost curve, I use two variables, capacity and UEC, with the assumption that the price is driven by both capacity and UECs:

$$\left(\frac{P}{P_0}\right) = e^{a} \times \left(\frac{UEC}{UEC_0}\right)^{b} \times \left(\frac{Cap}{Cap_0}\right)^{c} \text{(**Equation 1**)}$$

Where P=Price; UEC=Unit Energy Consumption; Cap=Capacity. P_0, Cap_0 and UEC_0 are the reference point. To calculate the relationship between price, UECs and Capacity, I performed a multivariable regression. To do regression analysis, I first took the natural log of both sides of Equation 1:

$$\ln\left(\frac{P}{P_0}\right) = a + b \times \ln\left(\frac{UEC}{UEC_0}\right) + c \times \ln\left(\frac{Cap}{Cap_0}\right) \text{(**Equation 2**)}$$

Then I set the ln(P/P0) as output variable, ln(UEC/UEC0) and ln(Cap/Cap0) as X variables and ran the regression. The linear regression determines the value of parameters a, b and c. If the regression results show correlation between price, UEC and capacity, I plugged the values of a, b and c back to the Equation 1 and computed the price value according to different UEC levels and capacity.

Cost-benefit evaluation

Once I established the relationship between efficiency and purchase price, I will determine cost-effectiveness according to the Cost of Conserved Energy (*CCE*) metric. CCE is the annualized additional cost to consumers needed to purchase higher efficiency appliance (compare to the baseline appliance) divided by the annual electricity savings (Equation 3). The unit of CCE is cost per kWh ($USD/kWh), which is the same unit as electricity price. I then compared the CCE to the retailed price of electricity paid by the consumer. If the CCE is less than the energy (utility bill) price, then that appliance shows cost-effectiveness to consumers.

$$\mathbf{CCE = q \times \frac{\Delta P}{\Delta UEC}} \text{ (**Equation 3**)}$$

where *ΔP* is the incremental equipment price and *ΔUEC* is the annual energy savings. The capital recovery factor, q, is the correlation between the discount rate and the life span of the appliances (Mahlia, et al, 2001). The recovery factor is given by:

$$\mathbf{q = \frac{d}{1-(1+d)^{-L}}} \text{ (**Equation 4**)}$$

In which d is the discount rate and L is the average lifetime of the appliance.

RESULTS

Australia

Table 1 reports the result of the multivariable regression analysis of each appliance analyzed. Some appliances, such as refrigerators, washing machines are divided into different groups according to the Australian appliance efficiency standards. R^2 value, coefficient and p-value are major indicators of whether the appliances show price-efficiency correlation. If the appliance shows a price-efficiency correlation, meaning it has large R2 value, right signs of coefficient and small p-value, then that appliance is "significant" and should be included in the CCE analysis. The refrigerators in group 5S, 6C and front load washing machine did not have price-efficiency correlation.

Table 2. Australian Residential Appliances analysis overview.

Country	Products	Group	number of models	R2	X variables	Coefficient	P-Value	Acceptable
Australia	Cloth Dryers		69	0.59	intercept	0.516835952	0.027	YES
					LN(Cap/Cap0)	3.195109306	6.18E-15	YES
					LN(UEC/UEC0)	-1.39741614	5.30E-07	YES
	Refrigerators	5T*	131	0.7584	intercept	0.077835625	0.19	YES
					LN(Cap/Cap0)	1.408979181	3.32E-07	YES
					LN(UEC/UEC0)	-0.866311037	1.28E-38	YES
		5B*	91	0.698	intercept	0.030069101	5.12E-01	YES
					LN(Cap/Cap0)	1.488572661	4.00E-20	YES
					LN(UEC/UEC0)	-0.287273312	5.55E-03	YES
		5S*	45	0.261	intercept	-0.459959445	5.71E-03	YES
					LN(Cap/Cap0)	1.655348732	3.34E-04	NO
					LN(UEC/UEC0)	-0.668728523	6.63E-02	NO
		6C*	50	0.818	intercept	0.167900343	0.01135316	NO
					LN(Cap/Cap0)	0.79168658	1.5479E-10	YES
					LN(UEC/UEC0)	0.22825866	0.13672139	YES
	Air Conditioners	Split	103	0.784	intercept	-1.1467088	3.76E-24	YES
					LN(Cap/Cap0)	2.743387717	7.21E-18	YES
					LN(UEC/UEC0)	-1.64446685	5.66E-11	YES
	Washing Machines	Front Load	82	0.254	intercept	0.006654678	9.78E-01	NO
					LN(Cap/Cap0)	1.500388832	4.59E-03	NO
					LN(UEC/UEC0)	-0.395467745	1.20E-06	NO
		Top Load	65	0.60	intercept	0.073928873	0.61527112	YES
					LN(Cap/Cap0)	1.377478958	8.0865E-14	YES
					LN(UEC/UEC0)	-0.332080853	0.00030298	YES
	Dishwashers		137	0.5	intercept	0.701476295	2.54E-06	YES
					LN(Cap/Cap0)	1.500141083	8.08E-19	YES
					LN(UEC/UEC0)	-1.680920687	1.22E-16	YES
	Television		124	0.84	intercept	0.727496026	3.80E-12	YES
					LN(Cap/Cap0)	1.544471104	6.99E-38	YES
					LN(UEC/UEC0)	-0.70351737	7.89E-11	YES

*Notes:

Group 5B: Refrigerator-freezer, both compartments automatic defrost (frost free), bottom mounted freezer

Group 5T: Refrigerator-freezer, both compartments automatic defrost (frost free), not side by side configuration or bottom mounted freezer

Group 5S: Refrigerator-freezer, both compartments automatic defrost (frost free), side by side configuration

Group 6C: Separate chest freezer, all defrost types

Based on the coefficient values above, I modeled the cost curves (Figure 1) of the appliances.

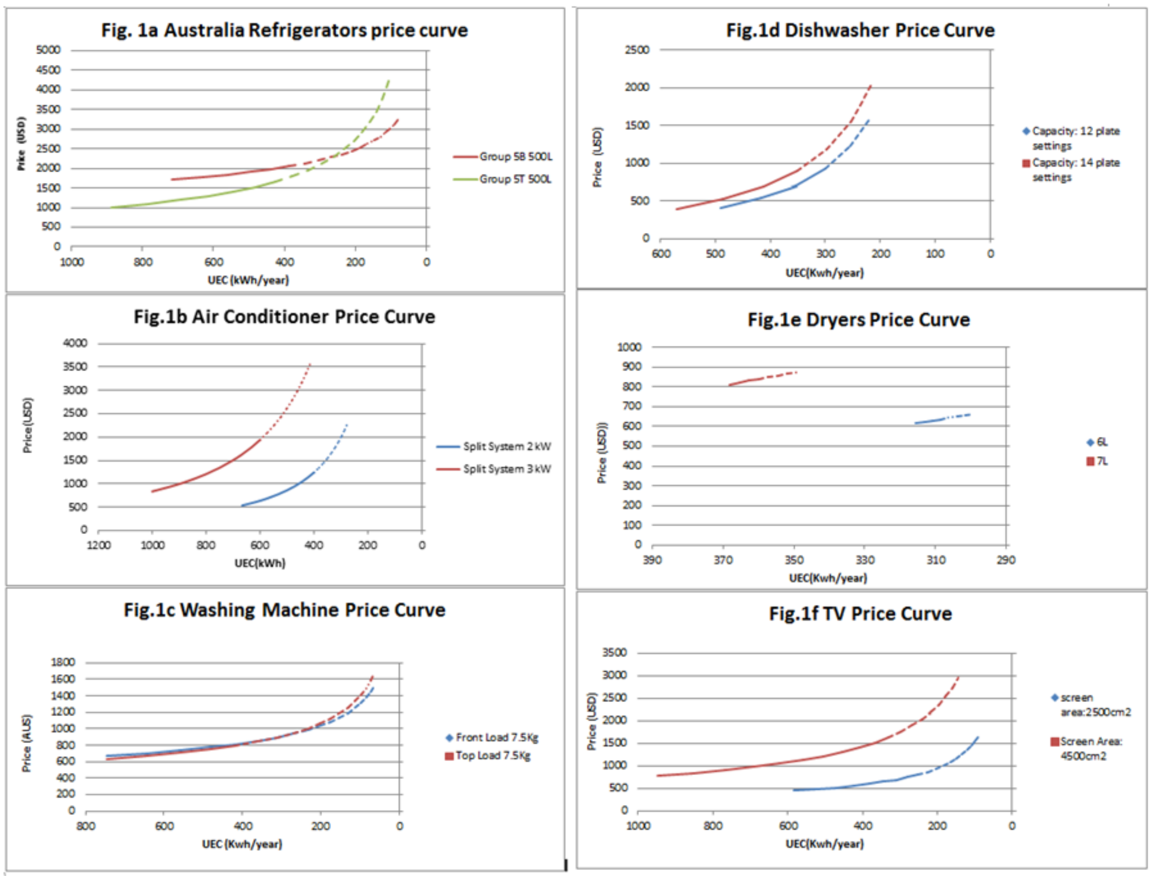

Figure 1. Australia Residential Appliances Price curves. *

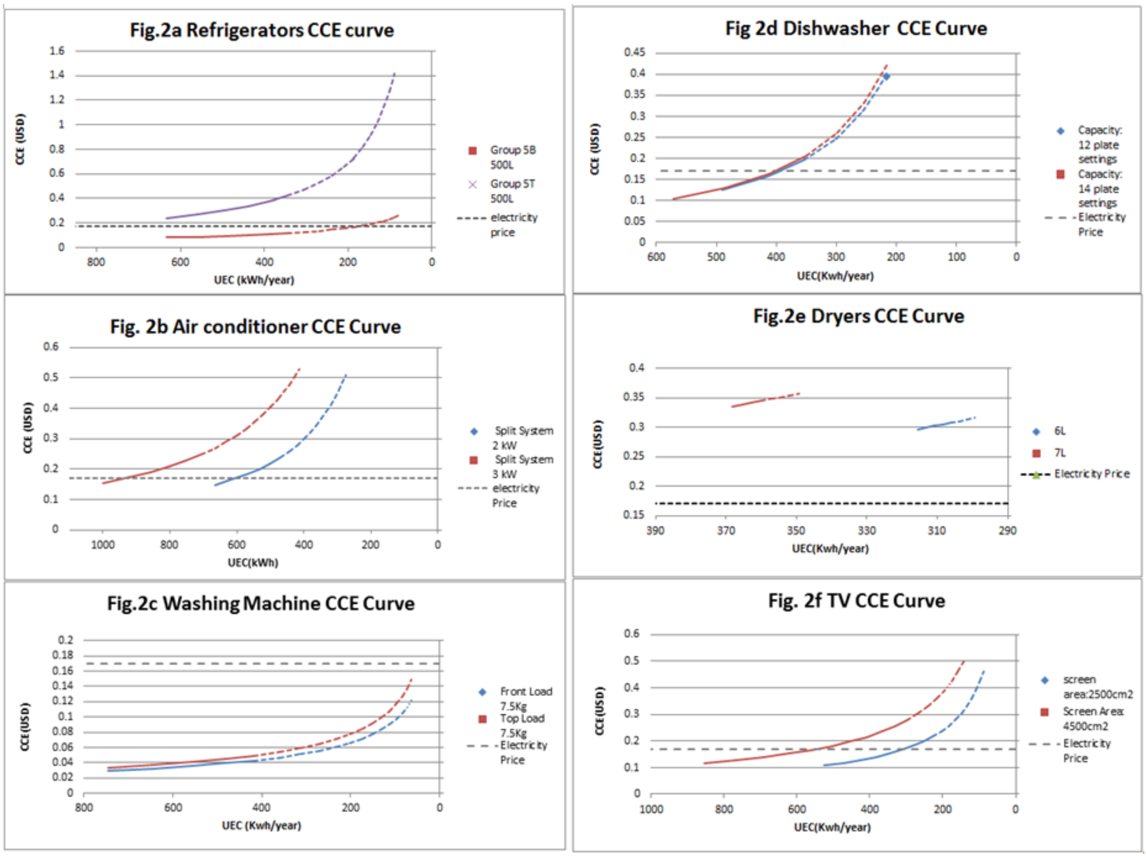

Figure 2. Australian Residential Appliances Cost of Conserved Energy. *

*In both Figure 1 and Figure 2, the solid lines represent the appliances are currently available in the market, the dots represent the imperial prices and CCE estimations based on the CCE equation.

The Australian government used a price of 0.17 USD/kWh(EES, 2010) in its estimation of energy costs of appliances. The appliance is cost effective if its CCE is lower than energy price and vice versa. Figure 2 shows that the refrigerators in group 5T and the dryers are not cost effective; refrigerators in 5B, washing machines and TVs have market potential to reach higher efficiency level; Dish washers and air conditioners have already reached maximum cost effective level in the current market (Table 3. Australia appliances energy efficiency improvements).

Table 3. Australia appliances energy efficiency improvements

Country	Product	Group	Capacity	Lifetime	Baseline UEC	Target UEC	Improvement	CCE
Australia	Regrigerators	5B	500L	15	716	186.0	74%	0.168
		5T	400L	15	637	564	11%	0.166
	AC	Split	2KW	12	727.3	615.4	15%	0.165
		Split	3KW	12	1090.9	1000.0	8%	0.15
	Washing Machine	Front Load	7.5Kg	15	862.5	35.5	96%	0.12
		Top Load	7.5Kg	15	862.5	54.8	94%	0.15
	Dish Washer		12 plate settings	15	576	416.2	28%	0.16
			14 plate settings	15	672	412.7	39%	0.16
	TV		2500cm2	7	584	310.4	47%	0.167
			4500cm3	7	949	560.4	41%	0.166

Japan

Only Japan air conditioner (AC) showed price-efficiency correlation (Table3). The AC price curve and CCE curve are summarized in **Figure 3.** Japan Air conditioner price curve and Cost of Conserved Energy curves

Table 4. Japan Residential Appliances analysis overview

Country	Product	Group	number of models	R2	X variables	Coefficient	P-Value	Acceptable
Japan	**AC**	Split	147	0.41	Intercept	0.43762504	1.00608E-09	YES
					LN(Cap/Cap0)	2.36314082	5.80162E-06	YES
					LN(UEC/UEC0)	-1.3554838	0.000452218	YES
	oil water boiler		361	0.42	Intercept	1.83140568	1.2208E-90	YES
					LN(CAP/CAP0)	0.58937144	0.000920822	YES
					LN(UEC/UEC0)	0.5768861	3.31014E-37	NO
	gas water boiler		383	0.33	Intercept	1.75948828	3.54759E-39	NO
					LN(Cap/Cap0)	-0.0174773	0.847141927	NO
					LN(UEC/UEC0)	0.53132548	2.99697E-35	NO
	Refrigerators		420	0.73	Intercept	-0.3965773	0.082850615	YES
					LN(Cap/Cap0)	0.07000001	0.35614823	NO
					LN(UEC/UEC0)	1.18785219	4.24956E-43	NO
	Rice cooker		196	0.11	Intercept	1.9394858	1.33515E-27	NO
					LN(Cap/Cap0)	0.56689215	0.174076957	NO
					LN(UEC/UEC0)	-0.0073792	0.987367469	NO

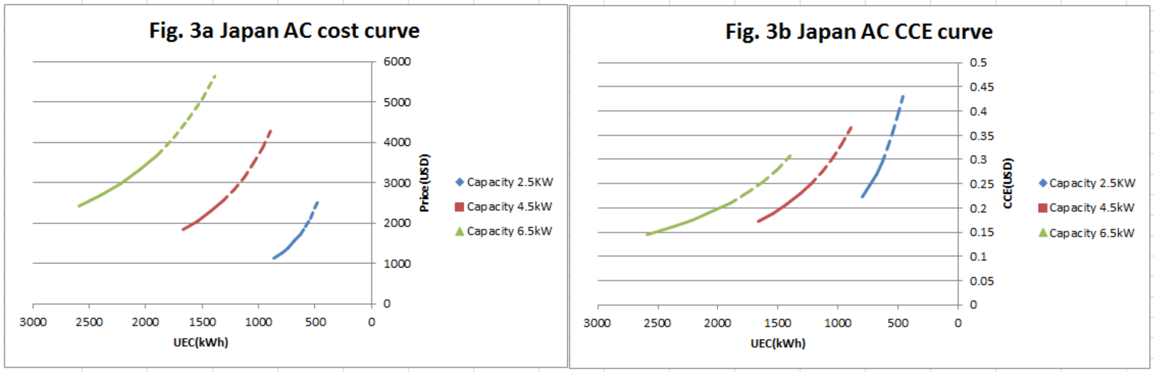

Figure 3. Japan Air conditioner price curve and Cost of Conserved Energy curves

Japanese government used 0.28 USD/Kwh (METI, 2010) for electricity price. Only 6.5kW and 7.5kW Air conditioner have energy efficiency improvements in the current market (Table 4):

Table 4. Japanese Air conditioner energy improvements

Country	Product	Group	Capacity	Lifetime	Baseline UEC	Target UEC	Improvement	CCE
Japan	AC	split	2.5kW	12	930	683	27%	0.27
			7.5kW	12	3200	1820	43%	0.26

Korea

In Korea, Air conditioner (AC), gas boilers and front load washing machines have shown price-efficient correlation (

Table 5. Korea Residential Appliances analysis overview).

Table 5. Korea Residential Appliances analysis overview

Country	Product	Group	number of models	R2	X variables	Coefficient	P-Value	Acceptable
Korea	AC	Split	400	0.6	Intercept	1.56	1.8E-111	YES
					LN(UEC/UEC0)	-0.82	8.73E-23	YES
					LN(CAP/CAP0)	1.52	3.41E-56	YES
	gas boiler		132	0.60	Intercept	-0.1839094	0.00553	YES
					LN(EEI/EEI0)*	8.78978542	3.86E-20	YES
					LN(CAP/CAP0)	0.34950624	3.75E-06	YES
	Refrigerators		453	0.46	Intercept	-0.5792013	0.01612	YES
					LN(UEC/UEC0)	0.3520177	0.040438	NO
					LN(CAP/CAP0)	0.76773037	4.56E-39	YES
	Rice cooker		231	0.073119	Intercept	1.03559536	0.001031	NO
					In(UEC/UEC0)	0.39039617	0.595503	NO
					LN(Cap/cap0)	0.04349443	0.930934	NO
	Washing Machine	Top load	100	0.214716	Intercept	0.32321006	0.163394	NO
					In(Cap/Cap0)	-0.9377522	0.001349	NO
					In(UEC/UEC0)	1.55960409	1.87E-06	NO
		Front Load	75	0.341551	Intercept	0.03918725	0.801745	YES
					LN(UEC/UEC0)	-0.3693334	0.095864	YES
					LN(Cap/Cap0)	0.72047357	1.2E-05	YES

*** EEI=Energy Efficiency Index, a measurement of energy efficiency as precentage in gas boiler**

Figure 4. Korean appliances price curves and cost of conserved energy curves.shows the price curve and CCE curve for these Korean appliances.

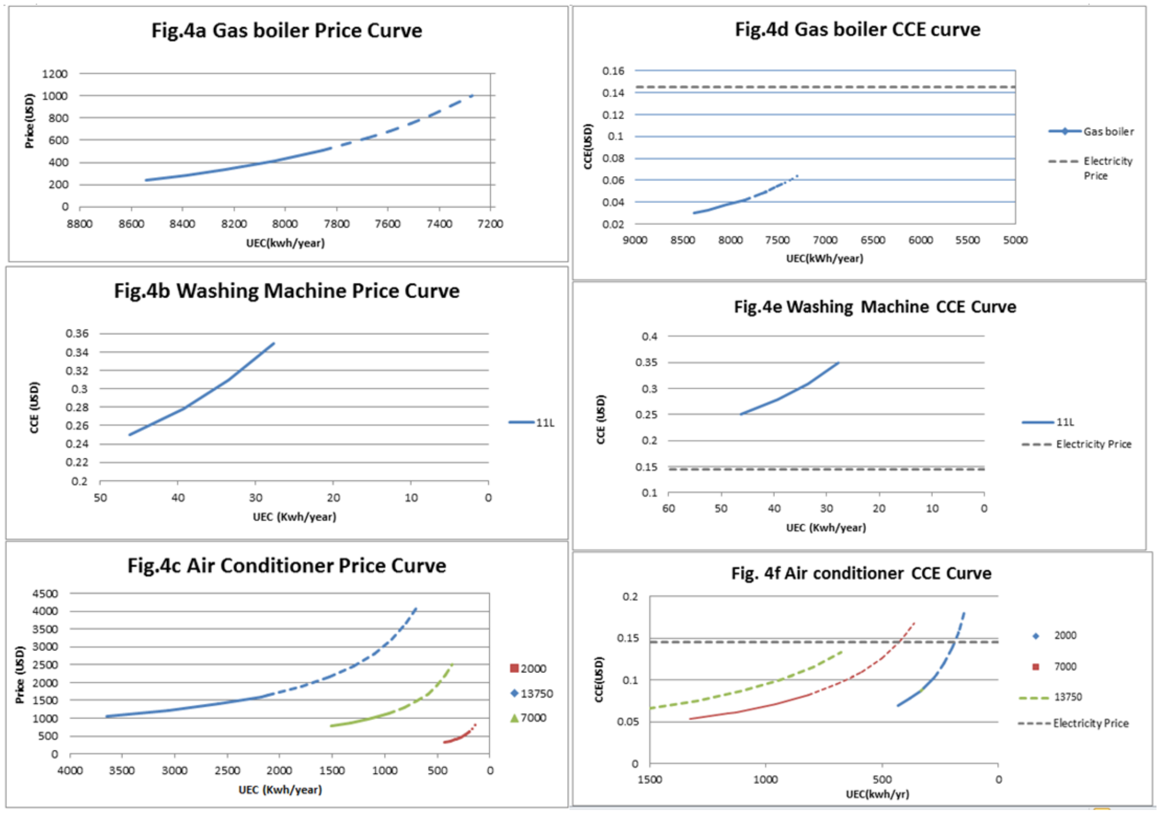

Figure 4. Korean appliances price curves and cost of conserved energy curves.

The Korean government used a price of 0.145 USD/Kwh (MKE, 2010) in its estimation of energy costs of appliances. Figure 4 shows that the gas boiler and the air conditioners are cost effective but have the market potential to reach for higher efficiency target. However, the front load Washing machine is not cost effective at all. Korean air conditioners and gas boilers have energy efficiency improvement potential because their highest cost-effective efficiency levels have not yet existed in the current market (Table 6. Korean appliances energy improvements).

Table 6. Korean appliances energy improvements

Country	Product	Group	Capacity	Lifetime	Baseline UEC	Target UEC	Improvement	CCE
Korea	AC	Split	< 4.0 kW	12	434.4	235.3	46%	0.2
		Split	4.0 kW -- 10.0 kW	12	1725.3	501.2	71%	0.13
		Split	10.0 kW -- 17.5 kW	12	3646.7	677.4	81%	0.128
		Split	17.5 kW -- 23.0 kW	12	2002	787.12	61%	0.127
	Gas Boiler			15	80%	99%	19%	0.08

DISCUSSION

In this article, I constructed price and CCE curves for the specific energy consumption for residential appliances in Australia, Japan and Korea. Applying CCE curve analysis to specific energy consumption of residential appliances reveals useful insights into the dynamics of energy efficiency improvements. I found that most appliances in counties with energy labeling programs, such as Australia and Korea, have shown positive price-efficiency correlations and demonstrate cost effective efficiency improvement to consumers. This finding highlights the importance of labeling programs in improving energy efficiency for household appliances cost effectively. The results of my study suggest that energy labeling programs are a powerful tool to encourage the market to be more energy efficient while being economically beneficial to consumers. I regard the CCE curve approach as applicable to and useful for analyzing the cost effectiveness of appliance energy standard policies.

Discussions of energy policy

The structure of the energy policy influences the appliances' cost-effective correlation. Comparing Table 1, 3 and 5, the results show that not all the appliances have cost-efficient correlations. The fact that the capacity and other features, such as more advanced functions, influencing the price more, skews this relationship. I found out that the appliances in Japan under the Top Runner program, showed less of a price signal for improving energy efficiency. In Japan, only one of the five (Table 2) appliances I analyzed showed price-efficiency correlations while in Australia and Korea, six out of six (Table 1) and three out of six respectively, displayed high price-efficiency correlations (Table 3). One explanation of the difference is that Japan is already very rigorous in terms of energy efficiency compared to other countries of the world and there is no much room for efficiency improvement (Murakami et al, 2006. Tojo, 2005). Another way to explain the difference between the Japanese market as opposed to those in Australia and Korea might be the difference between the structures of energy policies.

I observed two approaches to energy policy with regards to appliances. The first is the Top Runner approach while the other is the efficiency labeling program. Studies have shown each approach to effectively improve the energy efficiency for regulated appliances (EES, 2009. Tojo, 2005). However, each approach yields different in market price responses to efficiency.

Japan's Top-Runner approach

The purpose of the Top Runner approach is to motivate the manufacturers of energy consuming equipment to implement technological improvements that will increase the end-use energy efficiency of market goods (Nordqvist. J, 2006). In this system, efficiency targets are set based on the value of the most energy-efficient products at the time of the value-setting process. The sales weighted average efficiency for the manufacturer of regulated equipment is required to achieve the efficiency target by the target fiscal year (METI, 2010), which is usually between 4 to 8 years and depends on the consideration of future technological development and the development of products (Komiyama and Marnay, 2008). The Top Runner standard pulls the whole distribution of efficiency to a higher level. Under this method, if the demand is high for an appliance whose energy efficiency level is below the target, the manufacturer can still sell this product but must sell some high efficiency products so that its weighted-average efficiency can achieve the target level (METI, 2010).

Australia and Korea's energy MEPS and labeling program

Another way to improve equipment energy performance is through the Minimum Energy Performance Standard (MEPS) system, in which a minimum efficiency value is set and all the equipment in the market is expected to exceed the MEPS (METI, 2010). This efficiency improvement approach is more popular throughout the world. The Australian and Korean governments use the MEPS and Energy Rating Labels tools to improve appliances' energy efficiency. The government regulatory body sets and improves the MEPS level over time and the appliance is rated with different energy levels based on energy performance. With the energy rating labels, the energy consumption of an appliance becomes apparent to consumers. In Australia, studies show that the labeling programs have increased consumer awareness of energy efficiency and consequently, have created an increased demand for energy efficient products (E3, 2010).

Figure 5. Schematic View of "Top Runner Standards" and MEPS. (Source: Komiyama and Marnay, 2008)shows how the efficiency distribution of appliances in the market might appear under a Top Runner approach versus a MEPS as applied in Australia and Korea.

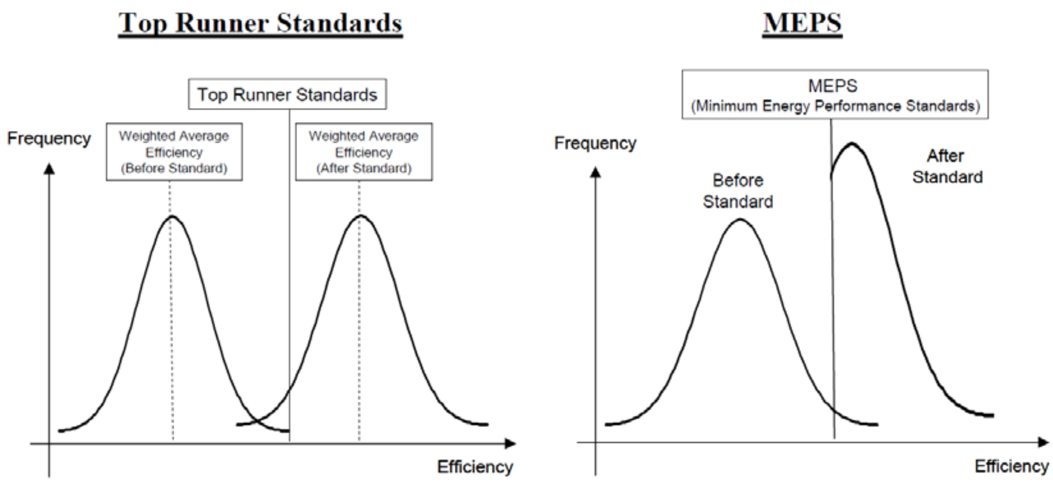

Figure 5. Schematic View of "Top Runner Standards" and MEPS. (Source: Komiyama and Marnay, 2008)

Both types of energy efficiency programs showed effectiveness of improving the energy efficiency of the appliances in the market (METI, 2010. E3, 2010.). They do not, however, bring the same efficiency impact on retail price. The results of this study indicate that most of the appliances in Australia and Korea show price-efficiency correlations, while the ones in Japan do not. In Australia and Korea, the energy label on the appliance can be used as a marketing tool. By making energy efficiency visible to consumers, the Energy Labeling Program creates an incentive for the manufactures to sell energy efficiency as a feature or investment of the equipment. This allows the manufacturer to increase the price as the equipment is becoming more efficient. However in Japan, the manufacturer has to sell the higher efficiency appliances at a lower price to increase the high efficiency equipment shipments and increase the average efficiency level to meet the standard. Another influence of the cost-efficiency relationship in Japan might be that the design priorities of certain appliances are not efficiency, but other features or functions of the appliance. For instance, some manufacturers argued that improving energy efficiency of rice cookers would compromise the quality of the cooked rice (Tojo, 2005). As a result, Japan market doesn't show price-efficiency correlation as much as the in other two markets.

Discussions of Cost of Conserved Energy

The CCE analysis results indicate that some appliances are cost effective while others are not, which provides policy opportunities to improve the MEPS level of appliances to be cost effective to consumers. Such appliances include the Australian refrigerator (Fig 2a), air conditioners (Fig.2b), dishwashers (Fig.2d), dryer (Fig 2e) and televisions (Fig.2f), the Japan air conditioners (Fig 3b) and the Korean gas boilers (Fig 4d) and air conditioners (Fig 4f). By establishing a more rigorous energy policy that would improve the MEPS level and eliminate the current lowest efficiency appliances, the high efficiency appliances in the market will be forced to increase production. As a result, the price of these high efficiency appliances will decrease due to increasing supply and technology learning (Weiss et al, 2009), which may lead to a decrease in CCE. This would allow the appliances that are not currently cost-effective to become cost-effective in the future and thus be more attractive to customers. Study showed that it is not hard for the manufacturers to meet the efficiency standard target; and by lowering the cost of conserved energy, consumers will be more motivated to purchase the higher efficient equipment (Tojo, 2005). Improving the efficiency and decreasing the CCE for these major residential appliance groups can have substantial national environmental and financial impacts, because these appliances groups have significant (over 50%) market shares (Table 7. Market share for cost-efficient potential appliances). Studies about cost of conserved energy for residential appliances in the US, China and India have shown that there are a lot of potential opportunities for improvements in efficiency standards while the efficient appliances still being cost efficient (McNeil et al, 2010, 2011). With this in mind, these appliances should receive more policy attention to make high efficiency appliance more cost-effective to costumers.

Country	Product	Group	Market
Australia	Refrigerators	5B+5T	61%
	AC	Split	47%
	Washing Machine	Front Load	36%
		Top Load	33%
	Dish Washer	12plates	25%
		14plates	44%
	TV	2500cm2	24%
		4500cm2	20%
Korea	AC	2kW	51%
		7kW	30%
		13.5kW	1%

Table 7. Market share for cost-efficient potential appliances

The cost effective analysis is subject to the energy price. The CCE analysis reveals a potential benefits to consumers if there's an increase in electricity price due to, for example, carbon tax. The increased electricity price will allow for more appliances to be cost-effective and consequently will both encourage the energy efficiency in the market and create extra carbon savings from residential appliances.

Discussion of limitations

In assessing the results, the limitation of this study should be addressed. First, there might be some deviation of the coefficients from multivariable regression. In multivariable regression, the X variables should be independent from each other. However, capacity and unit energy consumption (UEC) or efficiency are somewhat related to each other. For example, it may be easier/harder to make the appliance more efficient by increasing/decreasing the size. The correlations of the two variables might skew the value of the coefficient (Pazzani and Bay, 1999), and thus make the model less accurate. Second, the method simplifies the price curve by only including two factors; while many other factors that influence the retail price of the appliance are not considered in my study, such as specific functions of the appliance.

Meanwhile, it should be noticeable that the efficiency is improving and retail price of the appliance decreases over time due to technology learning (Weiss et al, 2009), even without policy implementation. Energy policy just accelerates this process.

Future Directions

Analysis for more countries will be covered in the future. The results of the study show that there are a lot of potential financial savings from improving energy efficiency of residential appliances. By implementing an effective energy policy, one country can save a lot of money and carbon emission. This is an opportunity for countries without energy efficiency program to implement one. More appliances and in more different countries can be analyzed in the future, not just residential sector but also commercial and industrial sector, as energy labeling program becomes more ubiquitous across the world.

Conclusions

The analysis of this study shows that implementing an energy efficiency policy can raise the energy efficiency level in the appliance market and provide significant net financial savings to consumers. Extra attention is needed for appliances that have larger potential of efficiency improvements and cost-effectiveness. More developing countries, especially countries in Asia where the market is growing rapidly, should consider developing appliance standard for both environmental and financial reasons. The impact of improving energy efficiency in appliances can be huge and it does not take a lot of effort to do—the efficient technologies exist; we just need to make it available and cheaper to the consumers.

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