Original Paper

Special Articles: Sustainable Energy Technologies

特集：持続可能なエネルギー技術

Assessments of Japanese Energy Efficiency Policy Measures in Residential Sector

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(Received November 12, 2013)

Eco-point program was one of the key programs intended for improvement in energy efficiency in residential sector in Japan. This paper estimated energy saving and CO₂ emission reduction effects of the program considering its impacts on changes in sales demand of appliances together with the expected energy efficiency improvements after the program. The estimated total effect of CO₂ reduction through the Eco-point program for air conditioners, refrigerators and televisions was 0.94 Mt-CO₂. The effect was much smaller than that estimated by the Japanese government. For the key aspect in the program for TVs, sensitivity analysis was also performed.

2009年から2011年の間で実施された家電エコポイント制度は、省エネルギー性能の優れた機器の購入に対してポイントが付与された支援策で、日本の家庭部門において試みられた省エネ政策の一つと捉えられる。多額の税投入も伴ったこの制度の省エネ/CO₂削減効果を評価することは重要だが、政府による既往評価では、各機器需要の時系列的傾向への影響及びそれに伴って関係しうる省エネ技術進展の影響が考慮されていない。本研究はこれらの点に対する分析も行い、より包括的な省エネ/CO₂削減効果の評価を試みた。その結果、エアコンと冷蔵庫、テレビのそれぞれについての措置をあわせた制度全体のCO₂削減効果は0.94 Mt-CO₂となり、既往評価よりも相当に低くなることが分かった。評価結果の低下につながったテレビに関する効果については、ポイント付与の対象を実際になされた範囲から変えた場合に表れる傾向の変化についてもあわせて検討した。

Key Words

Eco-point, CO₂ reduction, Energy efficiency, Residential sector

1. Introduction

The amount of CO₂ emissions from energy use in residential sector in Japan has been rapidly growing. One of the major policy measures for energy efficiency improvements has been the “Top Runner” Program, which is a regulatory scheme with mandatory standards for appliances. Several studies on its effectiveness have been pointing out its significance for improvements in energy efficiency¹⁾²⁾.

1.1 Eco-point program

Except for the “Top Runner” Program, Eco-point program, a kind of subsidy programs for appliance users, has been considered as another major policy measure. It had been carried out for about two years from May 2009 to March 2011. Under the Eco-point program, “Eco-points” was

issued to the consumers who purchased energy efficient air conditioners, refrigerators and televisions which had met certain criteria. The consumers could buy several goods and services by using the obtained “Eco-points”. Its purposes were not only a response measure to global warming but also a promotion of the terrestrial digital broadcasting TVs and revitalization of economy. The program was financed by a large amount of taxes of approximately 650 billion JPY.

1.2 Previous analyses

Ministry of the Environment (MOE)³⁾ and Board of Audit of Japan (BAJ)⁴⁾ estimated the CO₂ emission reductions by the Eco-point program by each technique (Table 1).

A shortcoming with the evaluation by MOE was that they had incorporated the effects of consumers' normal purchase behaviors of replacing old appliances with new ones into their calculations, which overestimated the emission reduction effects. BAJ pointed out the

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Table 1 The emission reduction effects by Eco-point program according to previous evaluations

(1000t-CO ₂ /year)	Evaluation by MOE ³⁾	Evaluation by BAJ ⁴⁾
Total	2730	210
Air Conditioner	793	77
Refrigerator	1285	53
TV	652	80

inappropriateness of the estimates by MOE, and reevaluated the effects and concluded that the effects are less than one tenth of those estimated by MOE. For both of the two estimates, however, the following points seem to be lacking and need to be further discussed:

- (a) Both of the estimates did not consider its emission reduction effect in time series, and only provide the effect of “ton per year” in unspecific periods.
- (b) Both of the estimates did not consider the impacts on changes in sales volumes of the appliances which the Eco-points had been provided.

Due to insufficient considerations of above (a) and (b), there are rooms to be discussed for more comprehensive estimations.

The purpose of this study is to evaluate the energy saving and CO₂ reduction effects more comprehensively by considering the program's impact on appliance sales volumes in time series and the combined impact with technology improvements as well.

2. Impact analysis on sales volumes

2.1 Recent trends of sales volumes

Fig. 1 shows monthly sales volumes of each type of appliances. The sales volume of flat-panel TVs tend to increase in summer season, end of years and apparently had a mid-term upward tendency with diffusion of terrestrial digital broadcasting systems. Those of room air conditioners and refrigerators increase in summer season, together with some increases in Decembers and Marches.

Fig. 1 Appliances monthly sales (2000-2011)^{5)~7)}

2.2 Method of analysis to analyze impacts of sales volumes

To examine the presence/degree of program's impacts on appliance demands, multiple regression analysis was conducted on monthly sales volume data from January 2000 to March/July 2011 for each type. Sales volumes were assumed to be explained by linear combinations of the several explanatory variables. For them, number of households, real disposable income per household, number of appliances possessed per household, cooling degree-day (for air conditioners and refrigerators), heating degree-day (for air conditioners) and dummy variables for months were adopted as a basis. Additionally, to consider irregular market behavior, i.e., possible influences by broadcasting system change and Eco-point program, we had introduced two un-sequential variables: “trend variable for broadcasting system change” and “Variable (dummy or trend type) for Eco-point program”.

Here, “trend variable for broadcasting system change” was a variable which we assumed to start with a value of 1 at December 2003 (the start of terrestrial digital broadcasting) and to increase 1 every month thereafter until July 2011 (the complete switchover from analog to digital system/termination of analog), to be 0 before/after those periods. “Variable (dummy or trend type) for Eco-point program” was a variable which we introduced to statistically examine the presence/degree of impact of the program on sales volumes. Note that cross terms for those variables were not introduced, which means each component was assumed to affect the market independently. Since the actual situations of influence on markets by the program are not well known, we assumed two cases. In Case-1, dummy variable was introduced to represent assumed “constant” degree of influence during the program, with the value of 1 from May 2009 to March 2011 and 0 otherwise. In Case-2, trend variable was introduced to represent assumed “expanding” influence which starts from 1 at May 2009 increasing 1 every month thereafter toward the end of the program (March 2011) and is 0 beyond the period of the program.

2.3 Results of multiple regression analysis

The results of multiple regression analysis in Case-1 and Case-2 are shown in Table 2 and Table 3 respectively. As seen in the Tables 2 and 3, the coefficients of the Eco-point program variable for flat-panel TVs are found significant both in Case-1 and Case-2. By contrast, those for air conditioners and refrigerators are not significant either in Case-1 or Case-2. However, note that detailed evaluations of program's impacts on the size, capacity, or other features

Table 2 Results of multiple-regression analysis in Case-1: assumption of “constant” influence

	Flat-panel TV		Air conditioner		Refrigerator	
Explanatory power (R^2)	0.808		0.941		0.738	
Variables	Coefficient	t-value	Coefficient	t-value	Coefficient	t-value
Number of households ⁸⁾	0.016	0.18	0.031*	2.24	-0.00868	-1.87
Real Disposable income ⁹⁾	1.049*	4.66	0.00701	0.081	0.157*	4.07
Units possessed per household ¹⁰⁾	-1066×103	-1.26	-260×103	-1.79	-856×103	-1.73
Eco-point program	$317 \times 103^*$	2.974	-26487	-0.84	-12286	-0.67
Broadcasting system change	18423*	3.496	NA	NA	NA	NA
Cooling degree-day ¹¹⁾	NA	NA	2495*	6.83	15678 *	13.8
Heating degree-day ¹¹⁾	NA	NA	1061*	6.76	NA	NA
Constant	1262×103	0.418	-728×103	-1.83	$1732 \times 103^*$	3.58

The asterisks (*) indicate statistical significances at 5% level.

Table 3 Results of multiple-regression analysis in Case-2: assumption of “expanding” influence

	Flat-panel TV		Air conditioner		Refrigerator	
Explanatory power (R^2)	0.843		0.941		0.741	
Variables	Coefficient	t-value	Coefficient	t-value	Coefficient	t-value
Number of households ⁸⁾	0.0344	0.41	0.0163	1.25	-0.00727	-1.69
Real Disposable income ⁹⁾	0.915*	4.46	0.41*	2.16	0.157*	4.10
Units possessed per household ¹⁰⁾	-826×103	-1.08	-131×103	-0.92	-946190	-1.96
Eco-point program	42082*	6.34	2377	1.13	-1605	-1.34
Broadcasting system change	15206*	3.19	NA	NA	NA	NA
Cooling degree-day ¹¹⁾	NA	NA	1852*	8.79	1570*	13.9
Heating degree-day ¹¹⁾	NA	NA	107.8	0.27	NA	NA
Constant	-86×103	-0.031	-460×103	-1.24	$1772 \times 103^*$	3.69

of appliances have not been carried out in this analysis.

As to analysis on TVs, the coefficients of broadcasting system change variable were also found significant. While accurate decomposition of the mixed influences of the program and the broadcasting system change is practically difficult, it seems reasonable to a certain extent to have discussions based on the results above since coefficients of both of them were found statistically significant.

2.3.1 Estimated sale volumes of flat-panel TVs

By applying the estimation model above, the sales volumes of flat-panel TVs were estimated from FY2000 to FY2011. Estimated values are shown in Fig. 2 together with

the corresponding actual sales volumes.

Deviations between the estimated and the actual values in FY2011 were resulted from the difficulty in modeling the actual market. While some of consumers in reality might have replaced old TVs with new ones in reaction to the system change late after the complete switchover (July 2011), the model had simply assumed that all reactive purchases to the switchover should have occurred beforehand. However, the values for FY2011 do not directly affect the estimations of emission reduction effects which are represented by the differences between with and without the Eco-points, while the estimated sales volume in FY2011 does not meet well with the actual one.

2.3.2 Program's impact on sales volumes (TVs)

Based on the estimation model above for Case-1 and Case-2, estimated impacts of the Eco-point program on the sales volume of TVs were calculated by comparing the estimated values with/without the program. Table 4 shows the results for each case. We see that Case-2 not only has a greater explanatory power (R^2) than Case-1, but it represents closer values to the actual than Case-1 during the program's period (FY2009/FY2010). In the following assessments for the program we refer to the estimation results by Case-2.

Fig. 2 Estimated annual sales volumes in Case-1 and Case-2

Table 4 Estimated impacts of Eco-point program on the sales volume of TVs (unit: 1000 units)

	Case-1	Case-2
FY 2009	15766	2777
FY 2010	18799	8837
Total	34565	11615

3. Assessments of energy saving effects

3.1 Energy efficiencies of appliance introduced during the program periods

Energy efficiencies of appliance products introduced during the program periods are shown in Table 5. Those are sales-volume- weighted averages using the data for each size or capacity category. While “Average” values represent averages of all models (from the list ¹²⁾), the values of “program average” incorporates averages of the eligible models which met program’s efficiency criteria for the proportions of the numbers of eco-point issued to the total sales volumes during the periods ^{5) ~ 7)}.

3.2 Examination on energy saving effect

3.2.1 Air conditioners and refrigerators

1) Methods

We firstly present the analysis procedure for air conditioners and refrigerators. No significant impacts by the program on the sales volumes were observed, and the rebound effects were not assumed in time series. Therefore, following improvements in energy efficiencies do not affect the emission reductions by the program, and our discussions will be focused only on the effects of newly introduced appliances during the program. The energy saving effects resulting from differences in energy efficiencies of them are supposed to be obtained by their usages and to remain until the end of their lifetime.

The probability distribution functions for remaining appliances were assumed based on Weibull distribution function. Their parameters were determined by fitting using least-squares method to a vast amount of cumulative survey data collected on actual lifetimes for each type ¹³⁾. Based on the determined functions, transitions of the number of remaining appliances were then estimated to calculate the energy saving effect in future years. The estimated CO₂ reduction effects in each year were

calculated by multiplying value of energy savings and the CO₂ emission coefficient.

2) Results

The estimated energy savings for air conditioners and refrigerators are shown in Fig. 3. The effects last for approximately 20 to 30 years, though they decay with decreasing number of program-related appliances. Fig. 4 shows the cumulative CO₂ reduction effects. By FY2040 where effects would be almost saturated, the estimated cumulative CO₂ reductions of air conditioners and refrigerators reach 1.2 and 0.93 Mt-CO₂, respectively.

3.2.2 TV

1) Methods/Assumptions

Our estimation of energy saving effects of TVs were obtained by subtracting the estimated energy consumptions by stocks in the case with the Eco-point program from those without the program. Estimation of the energy

Fig. 3 Estimated energy saving effect of air conditioner and refrigerator

Fig. 4 Estimated cumulative CO₂ reduction effect

Table 5 Energy efficiencies of products introduced during the program period (unit: kWh/year)

(FY)	TVs			Air conditioners			Refrigerators		
	Average	Program average	Diff.	Average	Program average	Diff.	Average	Program average	Diff.
2009	127	123	4	1193	1176	17	377	350	27
2010	98	95	3	1048	1045	3	321	317	4

consumption by stocks in each case was based on the following assumptions:

- The numbers of old type analogue TVs replaced by new ones yearly in and before FY2012 are the same as total sales volumes of TVs in corresponding years.
- The lifetime tendency of new, flat-panel TVs are subject to a probability distribution function based on Weibull type distribution and the average usage year to be 20, since there isn't enough empirical data for them yet.
- As an adverse effect resulting from the impacts on sales volumes during the program (Table 4 (Case-2)), the sales volumes in the case with the program for the post-program periods (in FY2011 and FY2012) were assumed to be evenly lower than the case without the program, where the total sales volume from FY2009 to FY2012 should be equal in each case. Sales volumes in future years in and after FY2013 were calculated back from the assumed numbers of stocks. As for the stocks, the growing numbers of flat-panel TVs possessed per household were assumed to be saturated at 2.4, which is approximately the same as the empirically observed number for the old type TV case, and then an estimated logistic curve was determined by fitting to the survey data¹⁰⁾. The numbers of stocks were then obtained using estimated numbers of households¹⁴⁾.
- As for energy efficiencies of TVs newly introduced in the future, average annual improvement rates measured from 2011 to 2013 in each size category¹⁵⁾ was applied. Market shares in display sizes are considered to moderately follow the increasing trend curve. Sales volume of plasma display type keeps 10% in the market.

2) Results

Estimated effect of energy saving is shown in Fig. 5. Although positive effects of energy saving are estimated from FY2009 to FY2011, the effects are negative in FY2012 and thereafter. The CO₂ reduction effects are shown in Fig. 6. The evaluated cumulative CO₂ reduction until 2040 was minus 1.2 Mt-CO₂ which means additional emissions were

Fig. 5 Estimated energy saving effect of TVs by the program

Fig. 6 Estimated CO₂ reduction effect of TVs

induced considerably by the program.

4. Discussion on characteristics of effects

4.1 Conditions for positive energy saving effect

The following implications were given from the results obtained in section 3.2.

- In the case where increases in sales volumes by the program are not expected:

Effects obtained from differences in energy efficiencies of newly introduced appliances during the program period keeps generating positive effects though they gradually decay. The expected effect would be larger if assumed durability of appliances was longer.

- In the case where increases in sales volumes by the program are expected:

The energy saving effect by the program will be smaller than that without the program if higher improvements in energy saving of the appliance in the post-program period and stimulations of the sales increases are expected. Determining whether the effect becomes positive or negative depends on the magnitude relation between the degree of improvements in efficiency of the introduced products during the program and transition of those on average basis after the program. In this program for TVs, while the former is relatively small at 3-4 [kWh/y], the latter is much larger (difference between average values of FY2009 and FY2011 was 40 [kWh/y]). Consequently, the energy saving effect falls greatly to get negative and then by continuous usage of appliances with relatively low efficiencies for a considerable period of time, cumulative energy saving effect also becomes negative. (Even if sales increases are stimulated by the Eco-points, positive saving effect can be obtained on the condition that the former is greater than the latter. See section 5).

4.2 Summary of assessments/studies

4.2.1 Total CO₂ reduction effects

Fig. 7 shows the total estimated effects of three types of appliances. Though the estimated cumulative reduction effect were positive, values were considerably affected by the negative effect by the TV, which turns the upward curve to downward in FY2025. The estimated cumulative CO₂ reduction effect is 0.94 Mt-CO₂ in FY 2040. This corresponds to about 0.5% of CO₂ emission from residential sector in Japan in FY2010 (172 Mt-CO₂).

4.2.2 Comparison with the existing evaluations

The average annual CO₂ reduction effects estimated for air conditioners, refrigerators and TVs are 65, 54 and -48 (1000t-CO₂) respectively, which are estimated based on the assumptions of product lifetime of 15, 14 and 20 years. Compared with the existing evaluations as shown in Table 1, the estimates of the reduction effects in this study are smaller than those by MOE³⁾ for all the three kinds of appliances. The estimates for air conditioner and refrigerator are similar to those by BAJ⁴⁾; however, those for TV are negative and smaller than those by BAJ.

4.2.3 Economic efficiency of tax-paid subsidies

The amount of subsidy paid per CO₂ reduction is shown in Table 6. As for the cases of air conditioners and refrigerators, those effects were around 50 to 60 thousand JPY/t-CO₂. Considering the prices of CO₂ emission credit

Fig. 7 Estimated total reduction in CO₂ emissions of three kinds of appliances

Table 6 Subsidy paid per CO₂ reduction

	CO ₂ reduction effect(cumulative, by 2040) (1000 t-CO ₂)	Subsidy paid (Billion JPY)	Subsidy paid per CO ₂ reduction effect (JPY/t-CO ₂)
Air Conditioner	1195.2	62.2	52,063
Refrigerator	931.2	56.1	60,241
TV	-1181.6	531.6	-449,950
Total	944.8	650.0	687,960

dealt in the EU ETS in 2009/2010 which corresponds to around 2 thousand JPY per ton, the estimated costs are several tens of times higher than the market price, though we cannot simply compare them on the ground that estimated “effect” were generated in the process of the cost transferences by paying tax and they differ from the case of direct cost for countermeasure itself. As for the case of TV, although the amount of subsidy paid was as high as eight to nine times greater than that for the others, the effect was estimated as negative, namely adverse effect for the CO₂ reduction. The amount of its additional CO₂ emission effect was about the same as, or greater than the amount of reduction effects by others. Considering the program as a total, while the effect was estimated as positive, it was greatly affected by the cost/effectiveness for TVs, that is the negative effect and the large amount of subsidy paid for it. The total subsidy paid per CO₂ reduction effect was ten times even higher than those estimated for air conditioners and refrigerators. Those costs were considerably high and thus the program is regarded as inferior in terms of economic efficiency for the purpose of CO₂ reduction.

5. Sensitivity analysis on the effects by assumed different settings of program

As we see in Table 5, the condition where only a slight differences, i.e., 3%, in energy efficiency between the “average” and “program average”, the actual program’s criteria were not severely set (points were issued for products having four or more stars on their eco-labels for most of the time), which led high portions of the “eligible” models in the market (88% in 2009 or 98% in 2010¹²⁾). Here, based on the assumed conditions where higher criteria were set, their responses to effectiveness were calculated, though attention should be paid that possible change in sales volumes might be occurred by modifying the criteria.

Two cases, Case-A and Case-B, were considered in this study; in Case-A, eco-points should be issued only products having five stars, while in Case-B, more severely, for only upper half models in terms of energy efficiency for each size category.

Estimated CO₂ reduction effects in Case-A and Case-B are shown in Fig. 8. Larger effects are observed compared with the base case which assumed that the eco-points were issued in the actual manner. While negative effects were still slightly seen in Case-A, no negative effects were found in Case-B reflected by its severer criteria. As it turned out, positive energy saving and CO₂ reduction effects could be obtained by establishing better criteria even in the case where sales volumes were influenced by the program.

Fig. 8 Estimated CO₂ reduction effect in Case-A and Case-B

6. Conclusions

The CO₂ reduction effect by the Eco-point program was estimated to be 0.94 Mt-CO₂. Average annual CO₂ reduction effect was found much smaller than that estimated by the government. The results of sensitivity analysis suggested effects can be improved if they set more appropriate criteria for issuing eco-points.

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