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Energy Efficiency Regulation and R&D Activity: A Study of the Top Runner Program in Japan

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ABSTRACT

The Top Runner Program, a new approach to enhancing the energy efficiency of appliances and vehicles, has been introduced in Japan. In this paper an empirical analysis of the impact of the program and the labeling systems on firms' R&D efforts is carried out. The results show that the Top Runner Program and the labeling system for appliances led to increases in R&D expenditures by appliance producers. The program combined with the labeling system caused a 9.5% increase in appliance producers' R&D expenditures. However, the Top Runner Program and the labeling system for motor vehicles had little or even a negative effect on the innovative activity of motor vehicle manufacturers. R&D expenditures by motor vehicle producers may have increased in response to the exhaust gas regulation for diesel-powered vehicles rather than the energy efficiency regulation.

Keywords**:** *Top Runner Standards*, *Energy Efficiency*, *R&D*

1. Introduction

As the literature on the economics of environmental policy has often discussed, technological change is one of the critical factors for solving long-term environmental problems such as climate change.[1] Research and development (R&D) activities by firms play a significant role in determining the rate and direction of technological change. In theory, to what extent firms' innovative activities are spurred depends on the choice of environmental policy instruments, and it has been recognized that market-based instruments can provide firms with more powerful incentives to develop or adopt new pollution control technologies than command-and-control regulations. Recently market-based approaches such as emission taxes and tradable permits have been introduced (Stavins [2]). To combat climate change, several member states of the European Union (EU) adopted carbon taxes in the 1990s and the EU Emissions Trading Scheme was launched in January 2005. While the introduction of market-based instruments for reducing carbon dioxide emissions makes energy efficiency investments more beneficial for consumers and firms, there are obstacles that dampen their incentives to reap gains from energy saving potentials: search and information costs of energy efficiency measures, capital market failure that prevents firms investing more energy-efficient processes, and uncertainty about the long-run value of energy savings. Stern [3] claims that regulatory measures such as performance-based regulations and design standards can be an effective policy response to the obstacles, showing examples of successful programs including the Corporate Average Fuel Economy (CAFE) standards in the United States and the Top Runner standards in Japan.

In April 1999, the Top Runner Program, the aim of which is to reduce energy consumption in the household and transportation sectors, was introduced by a revision of the Law concerning the Rational Use of Energy. The driving force for the Japanese government to carry out this revision was the third conference of the parties to the U.N. Framework Convention on Climate Change in 1997. The conference led to the Kyoto Protocol, which compelled developed countries including Japan to take measures for reducing greenhouse gas emissions.

The Top Runner Program requires manufacturers of energy-using products to meet the Top Runner standards, which are future energy efficiency requirements based on the best performance of current technologies. The standards are applied to selected groups of energy-using products. At the start of the program, nine groups of appliances and vehicles such as air conditioners, cathode-ray

[1]For a comprehensive survey of issues related to technological change and the environment, see Jaffe *et al*. [1].

tube television sets, video cassette recorders, and passenger vehicles were selected. As of April 2007, the product groups to which the Top Runner standards are applied are as follows: gasoline/diesel/LPG passenger vehicles, air conditioners, fluorescent lights, cathode-ray tube/liquid crystal display/plasma television sets, copying machines, computers, magnetic disk units, diesel/gasoline freight vehicles, video cassette recorders, DVD recorders, electric refrigerators, electric freezers, gas/oil space heaters, gas cooking appliances, gas water heaters, oil water heaters, electric toilet seats, vending machines, oil-filled/molded transformers, electric rice cookers, and microwave ovens. Under this program, the regulatory agency uses the highest efficiency of an energy-using product achieved by a manufacturer as the basis of a new energy efficiency standard for the product.[2] Other manufacturers in the market are required to meet the new (Top Runner) standard within a certain period. More specifically, each firm must make sure that the weighted average of energy efficiency of products included in a category the program designates meets the standard within a fixed time limit. Thus, the Top Runner Program can provide firms with incentives to develop more energy-efficient products which can ensure that they will comply with the standard.[3] In addition, the program may have an effect on R&D activity: it is likely that firms will invest more in their R&D activities to be a ''top runner'' – the first to achieve the highest energy efficiency if it is burdensome for manufacturers except the top runner to achieve the highest efficiency established as a mandatory standard. The program might be able to provide manufacturers with more powerful incentives to develop energy-efficient products as compared with existing approaches such as minimum and average energy standards.

There are data suggesting how effective the Top Runner Program has been in enhancing the energy efficiency of the products.[4] A trend in electricity consumption by air conditioners illustrates the effect of the program on energy efficiency. The average annual electricity consumption of air conditioners was 1,068 kWh in 1999 and was cut down to 882 kWh in 2006: after the introduction of the Top Runner Program, a 17.4% reduction in electricity consumption was realized. A change in the electricity consumption of cathode-ray tube televisions (CRT-TVs) also suggests the effectiveness of the program. The average electric power consumption of CRT-TVs in active mode decreased gradually, and so did the average annual electricity consumption. While the average annual electricity consumption of the 1999 models is 201 kWh, the 2006 models, on average, use 144 kWh – a 28.4% reduction compared with the 1999 models.

The aim of this paper is to explore whether the Top Runner Program, a new approach to enhancement of energy efficiency, can promote the development of products using less energy. More specifically, an empirical analysis is carried out in order to investigate whether the program could spur R&D activities by Japanese appliance and motor vehicle manufacturers. The paper is organized as follows. Section 2 presents a brief review of empirical studies on the effects of energy efficiency standards or the relationship between environmental regulation and innovation. Section 3 provides the model and data that are used to measure the effect of the Top Runner Program on R&D expenditures by the Japanese manufacturers. Section 4 presents and discusses the results of the empirical analysis. Section 5 offers concluding remarks.

2. Related Literature

There are several articles examining the impacts of energy efficiency standards on the fuel economy of vehicles or the consumption of electricity by home appliances. In the United States, the Energy Policy and Conservation Act of 1975 established mandatory fuel economy standards for automobiles and light trucks, which are known as the CAFE standards. Greene [4] shows that the standards were a binding constraint for many manufacturers and were nearly twice as effective for improving fuel efficiency as gasoline prices. Goldberg [5] estimates the effects of the CAFE standards on consumers' behavior and automobile prices and sales, combining a demand side model of vehicle choice and utilization with a supply side model of oligopoly and product differentiation. According to the estimates, changes in fuel costs tended to shift consumers' choices toward more fuel efficient vehicles, and producers primarily bore the cost of the CAFE regulation. Newell *et al.* [6] develop a methodology for empirical analysis of the induced innovation hypothesis to measure the effects of energy prices and government regulations on the energy efficiency of room air conditioners, central air conditioners, and gas water heaters. Their findings indicate that mandatory minimum efficiency standards and energy price changes affected the energy efficiency of these appliances, while a large portion of efficiency improvements were autonomous. Greening *et al.* [7] use the hedonic pricing method to

[2]The Energy Efficiency Standards Subcommittee, established under the Advisory Committee for Natural Resources and Energy (an advisory body to the Minister of Economy, Trade and Industry), deliberates and makes decisions on the Top Runner standard setting.
[3]For more detailed information on the Top Runner Program, see the Energy Conservation Center, Japan (ECCJ) website at http://www.eccj.or.jp/top_runner/index_contents_e.html (accessed April 26, 2007).
[4]See the ECCJ website.

examine the effects of efficiency standards on the quality-adjusted prices of refrigerators. They show that the standards resulted in declines in the quality-adjusted prices and efficiency improvements that brought about a welfare gain for consumers.

Recently empirical studies on the effects of environmental policy instruments on technological innovation have emerged. Some of the studies address the measurement of the impacts of the Clean Air Act (CAA) in the United States on technical progress in scrubbers used at power plants. Bellas [8] finds no significant technological advances in scrubber technology under the new source performance standards of the CAA. In contrast, Lange and Bellas [9] show that the sulfur dioxide (SO_2) allowance trading system created by the 1990 Clean Air Act Amendments (1990 CAAA) caused reductions in the costs of purchasing and operating scrubbers. Popp [10] investigates the effects of command-and-control and market-based approaches on innovation in scrubber technology using data on electric utilities before and after passage of the 1990 CAAA. He estimates the impacts of these approaches on scrubber-related patent applications, finding that while innovation under command and control regime reduced the costs of operating scrubbers, the SO_2 allowance trading brought about improvements in the removal efficiency of scrubbers. The results suggest that the nature of innovation may change if the choice of environmental policy instruments is altered.

Debates on the relationship between environmental regulation and innovation have been developed with theoretical and empirical studies examining the Porter hypothesis (Palmer *et al*. [11]; Porter and van der Linde [12]; Simpson and Bradford [13]). Jaffe and Palmer [14] investigate how pollution abatement expenditures affected innovative activities in U.S. manufacturing industries. They find that R&D expenditures significantly responded to lagged pollution control costs. Brunnermeier and Cohen [15] indicate that increases in pollution abatement expenditures are significant determinants of environmental innovation by U.S. manufacturing industries, which is measured by the number of successful environmental patent applications. Hamamoto [16] employs an extended Cobb-Douglas production function in order to examine the impacts of environmental regulations on R&D spending and productivity in Japanese manufacturing industries, showing that increases in R&D investment stimulated by regulatory stringency have a significant positive effect on the growth rate of total factor productivity.

3. Estimation Model and Data

Even if highly efficient products are developed, they cannot diffuse without users' awareness of their own benefits from using them. The Top Runner Program is working with labeling systems contributing toward the diffusion of more energy-efficient appliances and motor vehicles. In 2000, the energy conservation labeling system for several categories of appliances to which the Top Runner standards are applied was launched. This labeling system provides consumers with information about to what extent appliances have achieved the standards.[5] A similar system of labeling for the energy efficiency of motor vehicles was introduced in 2004. If such labeling systems are effective, the demand for products with higher efficiency will grow: consumers may put forward the date of replacing appliances or motor vehicles that are old and less efficient, or more energy-efficient products will tend to attract environmentally conscious customers. On the other hand, the labeling systems will reduce the demand for less efficient products because consumers who obtain information about the energy efficiency level of each product will seek to buy products with higher energy efficiency. Thus, the labeling systems are expected to provide appliance and motor vehicle producers with the incentive to develop more energy-efficient products.

In order to examine the effect of the Top Runner Program and the labeling systems on R&D activity, the following reduced form equation is estimated.

$$\ln\left(R\&D_{i,t}\right) = a + b_1 \ln\left(SALE_{i,t-1}\right) + b_2\left(SALEGROW_{t-1}\right) + b_3 D_T + b_4 D_L + b_5 D_I + b_6\left(TREND\right) + u_{i,t}$$

where a is a constant, $R\&D_{i,t}$ is firm i's R&D expenditure at time t, $SALE_{i,t-1}$ represents the one-year lagged firm's sales used as a measure of the firm size, $SALEGROW_{t-1}$ is the one-year lagged growth rate of sales in the industry to which the firm belongs, D_T and D_L are dummy variables relevant to the Top Runner Program and the labeling system, respectively, D_I is a dummy variable for the motor vehicles industry, *TREND* represents a trend variable (treated as a linear time trend), and $u_{i,t}$ is a residual error term. *SALEGROW* does not have the form of logarithm because the data for the variable include negative numbers. The dummy variable D_T takes the value one in the years when the Top Runner Program has been implemented and zero in other years. Similarly, D_L is defined as $D_L = 1$ in the years when the labeling system has been introduced and $D_L = 0$ in other years. In the estimation, two types of D_L are used: D_{LA} for the labeling system for appliances and D_{LV} for the one for motor vehicles.

Numerous empirical studies have examined the relationship between firm size and innovation and found that

[5]For example, if a product is 20% more (less) efficient than the Top Runner standard, it has a label indicating ''120% (80%)''.

large firms have the advantage in innovation.[6] In the estimation, *SALE* is used to capture the effect of the firm size on the R&D expenditure. However, exaggerated emphasis on the role of firm size in R&D may be misleading because the relationship between firm size and innovative activity can vary across industries which have different technological and market conditions. Cohen *et al.* [18] show that the effect of overall firm size on business unit R&D intensity is statistically insignificant when inter-industrial differences in technological opportunity and appropriability are taken into account. While the importance of industry characteristics such as demand conditions, appropriability, and technological opportunity has been acknowledged, quantitative analysis of their influence on innovative activity has inadequately been carried out partly because reliable data necessary for empirical study are unavailable.[7] In this paper, demand conditions are measured with the one-year lagged growth rate of sales in each industry, and technological opportunity and appropriability are treated as unobservable industry characteristics. In the estimation, the industry characteristics are captured by a dummy variable D_I because sample firms that were selected for the estimation can be categorized into two industries: the motor vehicles industry and the electrical machinery manufacturing industry. The dummy variable takes the value one if a firm produces motor vehicles and zero otherwise.

Sample selection and data sources are as follows. Because the data for R&D expenditures by individual companies are published in their financial statements, only listed companies can be used as sample firms. In addition, R&D expenditure data for some companies are lacking for the past several years. Therefore, sample firms and years were selected based on consistency and availability of R&D expenditure data. The estimation uses a sample including thirteen Japanese firms producing air conditioners, fluorescent lights, cathode-ray tube television sets, copying machines, computers, magnetic disk units, video cassette recorders, electric refrigerators, and electric freezers and six Japanese firms manufacturing diesel/gasoline freight vehicles and gasoline/diesel/LPG passenger vehicles. The Top Runner standards have been applied to these appliances and motor vehicles since 1999. The labeling systems for appliances (air conditioners, fluorescent lights, cathode-ray tube television sets, electric refrigerators, and electric freezers) and motor vehicles were introduced in 2000 and 2004, respectively. While the sample was selected on the basis of data availability, it includes firms that have a large share of several domestic markets for appliances and motor vehicles. Of the six firms manufacturing motor vehicles, four had a 68% share of the market for automobiles (except light motor vehicles) and five a 91.7% share of the market for light motor vehicles in 2005. In addition, of the thirteen firms producing appliances, five had 88.1% of the electric refrigerator market in 2006, four 56.4% of the air conditioner market in 2005, and three 47.6% of the personal computer market in 2005.[8]

Firm-level R&D expenditure and sales data were taken from the consolidated financial statements. The sales data for the motor vehicles and electrical machinery manufacturing industries and the R&D deflator were obtained from *the Report on the Survey of Research and Development*. The deflator for the household final consumption expenditure of durable goods in the *Annual Report on National Accounts* is used for deflating the sales data. The empirical test uses the data of the nineteen firms during the period 1996-2005 (t = 1997, 1998, ··· , 2005).[9] The summary statistics of main variables used for estimation are presented in **Table 1**.

4. Results and Discussion

Table 2 reports results obtained using full sample. Column (1) and (2) of the table present the results of regressions using OLS with and without the industry dummy (D_I), respectively. Column (3) displays the result of a fixed effects model that treats firm-specific effects as unobservable factors that are constant over time but vary across firms. More specifically, the model contains firm-specific dummies to capture the effects of such unobservable factors. The analysis using the fixed effects model is reasonable if we can be confident that the differences between sample firms can be viewed as parametric shifts of the regression function. However, it is likely that firm-specific constant terms are randomly distributed across firms. In such a case, it is appropriate to use a random effects model that contains a random disturbance to represent firm-specific effects. Column (4) of **Table 2** presents the result of a regression using the random effects model.

As shown in **Table 2**, the coefficient of the Top Run-

[6]There are several justifications for the large firm advantage in innovation. First, there are scale economies in knowledge production. Second, a large volume of sales is needed in order to increase returns from R&D because the fixed costs of innovative activity are spread over the volume of sales. Third, capital market imperfections necessitate holding internally-generated funds for R&D. Such funds are likely to be available for large firms. Finally, large firms can afford to prepare activities complementary to R&D (such as advertising and customer service). The empirical literature has mainly explored whether R&D increases more than proportionately with firm size, finding a positive and often proportional relationship between firm size and innovative activity (Cohen [17]).

[7]Cohen *et al*. [18] and Cohen and Levinthal [19] use survey-based measures of technological opportunity and appropriability conditions.

[8]These market share data come from Nikkei Sangyo-Shinbun [20,21].

[9]The scope of products to which the Top Runner standards are applied was extended in 2006. This paper uses the data during the period before 2006 because it aims to measure the effect of the original version of the Top Runner Program on R&D activity.

Table 1. Summary statistics of main variables.

Variable	Mean	Standard Deviation	Description
R&D	2354.02	2867.51	Firm's R&D expenditure (10^8 yen)
SALE	46362.12	27918.92	Firm's sales (10^8 yen)
SALEGROW	7.272	9.141	The growth rate of industry sales (%)
D_T	0.778	0.417	Dummy for the Top Runner Program
D_{LA}	0.456	0.500	Dummy for the labeling system (appliances)
D_{LV}	0.070	0.256	Dummy for the labeling system (motor vehicles)
D_I	0.316	0.466	Dummy for industries

Table 2. Effect of the Top Runner Program: Full sample.

Variable	(1) OLS with D_I	(2) OLS without D_I	(3) Fixed Effects Model	(4) Random Effects Model
Constant	–1.76656 (0.070556)***	–1.78111 (0.084149)***		–1.57845 (0.197252)***
ln(*SALE*)	1.13454 (0.015802)***	1.12541 (0.018808)***	0.876098 (0.108572)***	1.07420 (0.045369)***
SALEGROW	0.336893E–03 (0.101252E–02)	–0.102162E–02 (0.119241E–02)	0.474845E–03 (0.600851E–03)	0.266329E–03 (0.598047E–03)
D_T	0.056807 (0.030550)*	0.348565E–02 (0.035650)	0.042685 (0.018989)**	0.049528 (0.018165)***
D_{LA}	–0.287115E–02 (0.033042)	0.184215 (0.029094)***	–0.012131 (0.019898)	0.909417E–02 (0.019265)
D_{LV}	0.699752E-02 (0.043432)	–0.013928 (0.051730)	0.011011 (0.025709)	0.634664E–02 (0.025661)
D_I	–0.231009 (0.027528)***			
TREND	–0.027728 (0.630209E–02)***	–0.037766 (0.738182E–02)***	–0.016742 (0.591629E–02)***	–0.025949 (0.417749E–02)***
R-squared	0.969601	0.956468	0.990500	0.941508
Adjusted R-squared	0.968296	0.954876	0.988938	0.939368

Standard errors in parentheses. *** Significant at the 0.01 level; ** Significant at the 0.05 level; * Significant at the 0.1 level.

ner dummy is positive and significant at least at the 5% level in the fixed and random effects models. In OLS with the industry dummy, the coefficient of D_T is positive and significant at the 10% level, while that of OLS without D_I is insignificant. An *F*-test is carried out and the result rejects the null hypothesis that the firm-specific effects are all equal.[10] This suggests that the fixed effects model should be used rather than OLS. In addition, the Hausman test is conducted in order to make a choice between the fixed and random effects models. The result of the test is that the chi-squared statistic and *p*-value are 19.605 and 0.0001, respectively. This indicates that it is appropriate to adopt the fixed effects model. The coefficients of the labeling system dummies (D_{LA} and D_{LV}) are statistically insignificant in OLS with D_I and the fixed and random effects models, while OLS without D_I has a significant positive coefficient of D_{LA}. In sum, these results suggest that the introduction of the Top Runner Program stimulated R&D activities performed by appliances and motor vehicle manufacturers and that the labeling systems had little effect on the R&D activities.

The coefficient of *SALE* is positive and significant at the 1% level in all of the models, which is consistent with the findings of the existing literature about the relationship between firm size and R&D activity. The coefficient of *SALEGROW* is statistically insignificant, implying that the rate of sales growth in the industries may not be the prime determinant of innovation.

The result in column (1) shows that the industry dummy has a significant negative coefficient. This implies that unobservable industry characteristics may be one of the important factors for explaining the difference of the level of R&D expenditures between appliance and motor vehicle producers. In addition, the coefficient of the Top Runner dummy is significant in OLS with D_I but not significant in the one without D_I. This may suggest that there is a difference in the effect of the Top Runner Program between appliance and motor vehicle manufac-

[10]The *F* statistic is 29.057, which indicates that the null hypothesis is rejected at the 1% significance level.

turers.

Table 3 reports the results of regressions (OLS, and fixed and random effects models) using the data for the thirteen firms producing appliances. The significant positive coefficient for *SALE* supports the findings that larger firms have the advantage in innovative activity. *SALEGROW* has a negative impact on R&D, but the coefficient is statistically insignificant. The coefficients of the dummies for the Top Runner Program and the labeling system are positive and significant at the 10% level in column (2), and they are positive and significant at the 5% level in column (3). The result of an *F*-test indicates that the fixed effects model is more appropriate than OLS.[11] The result of the Hausman test is that the chi-squared statistic is 0.52722 and the *p*-value 0.4678, showing that the random effects model should be adopted rather than the fixed effects model.

The coefficient of the dummy for the Top Runner Program indicates the difference between the logarithms of actual and counterfactual R&D expenditures: the latter means R&D resources that would have been spent if the Top Runner Program had not been introduced. Using the coefficient, the ratio between the actual and counterfactual R&D expenditures can be calculated at $e^{0.043} = 1.044$. This result shows that the introduction of the Top Runner Program led to a 4.4% increase in R&D spending by appliance producers. Similarly, using the coefficients of the dummies for the Top Runner Program and the labeling system, the ratio of the actual R&D to R&D that would have been carried out without both the Top Runner Program and the labeling system can be calculated at 1.095. This means that the Top Runner Program combined with the labeling system resulted in a 9.5% increase in appliance producers' R&D expenditures.

These results suggest that both the Top Runner Program and the labeling system caused increases in R&D expenditures by appliance producers. An approach to energy efficiency enhancement such as the Top Runner Program combined with the labeling system may provide appliance producers with a strong incentive to develop more energy-efficient appliances.

Table 4 reports the regression results using the data for the six firms manufacturing motor vehicles. In all of the three models, there is a positive and statistically significant relationship between firm size and R&D spending, while the rate of sales growth has a positive but statistically insignificant impact on innovative activity. The coefficient of D_T is statistically insignificant in all of the models, and that of D_{LV} is negative and statistically significant at least at the 10% level in columns (2) and (3). The result of an *F*-test rejects the null hypothesis that the firm-specific effects are all equal, which recommends using the fixed effects model rather than OLS.[12] The Hausman test, the result of which is that the chi-squared statistic is 4.3412 with the *p*-value 0.1141, reveals that the random effects model is more appropriate than the fixed effects model. These show that the Top Runner Program had little effect on the R&D activities of motor vehicle producers and that the labeling system may have lessened their incentive to innovate.

A possible explanation for the results is that the Japanese major manufacturers of motor vehicles have been engaged in research on next-generation automobiles and have already allocated a large part of their R&D resources to the development of hybrid electric vehicles, battery electric vehicles, or fuel cell vehicles before 1999. It is likely that innovative activity in such research areas of automobiles may not have been positively affected by the introduction of the Top Runner Program and the labeling system.

Table 3. Effect of the Top Runner Program: Appliances.

Variable	(1) OLS	(2) Fixed Effects Model	(3) Random Effects Model
Constant	–1.72747 (0.064200)***		–1.70478 (0.141540)***
ln(*SALE*)	1.13039 (0.014302)***	1.02761 (0.138162)***	1.12507 (0.032750)***
SALEGROW	–0.376860E–03 (0.961847E–03)	–0.310573E–03 (0.639726E–03)	–0.373428E–03 (0.633842E–03)
D_T	0.043340 (0.032455)	0.037996 (0.022546)*	0.043064 (0.021439)**
D_{LA}	0.048123 (0.035271)	0.044034 (0.023869)*	0.047911 (0.023264)**
TREND	–0.035594 (0.604160E–02)***	–0.031197 (0.711456E–02)***	–0.035366 (0.419949E–02)***
R-squared	0.982578	0.993259	0.982578
Adjusted R-squared	0.981793	0.992101	0.981793

Standard errors in parentheses. *** Significant at the 0.01 level; ** Significant at the 0.05 level; * Significant at the 0.1 level.

[11]The *F* statistic is 13.072, which suggests that the null hypothesis that the firm-specific effects are all equal is rejected at the 1% significance level.
[12]The *F* statistic, 38.138, indicates that the null hypothesis is rejected at the 1% significance level.

Table 4. Effect of the Top Runner Program: Motor vehicles.

Variable	(1) OLS	(2) Fixed Effects Model	(3) Random Effects Model
Constant	–2.15986 (0.238263)***		–1.29809 (0.473024)***
ln(*SALE*)	1.15951 (0.053187)***	0.722204 (0.157512)***	0.963094 (0.107068)***
SALEGROW	0.104954E–02 (0.296589E–02)	0.112260E–02 (0.134443E–02)	0.108235E–02 (0.134429E–02)
D_T	0.514743E–02 (0.079802)	–0.020438 (0.037296)	–0.634453E–02 (0.036678)
D_{LV}	–0.076269 (0.081935)	–0.069923 (0.037203)*	–0.073418 (0.037165)**
TREND	–0.746177E–02 (0.019722)	0.011436 (0.011187)	0.102619E–02 (0.010011)
R-squared	0.911265	0.983672	0.909977
Adjusted R-squared	0.902022	0.979875	0.900599

Standard errors in parentheses. *** Significant at the 0.01 level; ** Significant at the 0.05 level; * Significant at the 0.1 level.

R&D activity in the motor vehicles industry will be affected by exhaust gas regulations. In the late 1990s, the Environment Agency of Japan planed to tighten the regulation for the emission of pollutants from diesel-powered vehicles. In 2000, the Director-General of the agency requested motor vehicle manufacturers to devote their efforts to developing exhaust gas control technologies in order for the new emission standards to be met as soon as possible (Environment Agency [22]). In order to examine the effect of this regulatory agency behavior on the innovative activity of motor vehicle producers, a dummy variable, D_R, is used instead of D_T and D_{LV} in the regression analysis for motor vehicles: D_R takes the value one in the years after 2001 and zero in other years. **Table 5** reports the results.[13] The coefficient of D_R indicates that the ratio of the actual R&D to R&D that would have been carried out without the new emission standards for diesel-powered vehicles is 1.1, suggesting that motor vehicle producers increased their R&D expenditures by 10% in order to comply with the standards.

Table 5. Effect of the exhaust gas regulation.

Variable	Fixed Effects Model	Random Effects Model
Constant		–1.12408 (0.448734)**
ln(*SALE*)	0.706778 (0.143515)***	0.935878 (0.102029)***
SALEGROW	0.288737E–03 (0.137340E–02)	0.161045E–03 (0.137225E–02)
D_R	0.096743 (0.037976)**	0.101238 (0.037925)***
TREND	–0.013601 (0.880800E–02)	–0.022963 (0.778272E–02)***
R-squared	0.984527	0.909794
Adjusted R-squared	0.981362	0.902430

Standard errors in parentheses. *** Significant at the 0.01 level; ** Significant at the 0.05 level.

[13]The result of the Hausman test is that the chi-squared statistic is 5.1525 and the *p*-value 0.0232, indicating that the fixed effects model should be adopted rather than the random effects model.

5. Conclusions

This paper investigates the effect of a new approach to enhancing energy efficiency on firms' R&D efforts. An empirical analysis is conducted in order to examine the impact of the Top Runner Program and the labeling systems on the R&D activities of Japanese appliance and motor vehicle manufacturers. The results show that the program and the labeling system for appliances had significant effects on the innovative activity of appliance producers. The Top Runner Program combined with the labeling system caused a 9.5% increase in appliance producers' R&D expenditures. However, the program and the labeling system for motor vehicles had little or even a negative effect on the innovative activity of motor vehicle producers, whose R&D expenditures may have increased in response to the exhaust gas regulation for diesel-powered vehicles.

The results of the empirical study imply that the effectiveness of an energy efficiency regulation such as the Top Runner Program may depend on the directions of research activities performed by firms manufacturing products to which the regulation is applied. The Top Runner standards for the fuel efficiency of motor vehicles may be ineffective in spurring research activity to develop next-generation automobiles. Encouragement of innovative activity with high-spillovers or serious difficulty in financing, such as the development of next-generation automobiles, may need technology policy including R&D subsidies, or other institutional settings to promote environmental R&D activity.

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