# Environmental regulation, R&D and Technological change

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# Environmental regulation, R&D and Technological change: Case on Japanese automobile industry

## Abstract

We empirically analyze environmental regulation on R&D expenditure and productivity in the Japanese auto industry using panel data from 1990 to 2002 of 75 firms, which includes assembling firms, manufacturing firms and body manufacturing firms. We find exhaust emission regulation stimulates R&D expenditure of the firm. Especially, the effect of the regulation on R&D expenditure of the assembling firms is larger than that of the parts manufacturing and the body manufacturing firms. Increase in R&D raises the productivity of the firms, while the stricter regulation does not directly raise the productivity in the auto industry. This indicates that the Porter Hypothesis is not supported. However, the stronger regulation is likely to increase the productivity indirectly, i.e. through the increase in R&D activity.

## 1. Introduction

The effects of environmental policy on investment and productivity have been analyzed in previous studies. Environmental regulation adds the constraint in their production possibility set. Thus, theoretically, environmental policy lowers the productivity of firms facing these regulations at least in competitive markets. On the other hand, Michael Porter emphasizes the agency costs, X-inefficiencies and managerial slackness and provides an alternative view on the effects of environmental policy to productivity and innovation initiated (see Porter and van der Linde, 1995). When firms face with strengthened environmental regulation, they seek potential technological innovation. This innovation activity (i.e., research and development (R&D) expenditures) is costly and the potential gain as returns for technological innovation was unnoticed until firms realize strengthened international competition.

This is known as Porter Hypothesis. If this hypothesis is valid, appropriate environmental regulation is not a burden for the firm but rather to increases the firms' competitiveness. As environmental problems gain more attentions in public policy, the discussion on the effects of environmental policy become more salient to academics as well as policy makers. There are abundant studies on this subject and this brought controversy, but has not yet resolved.

Some theoretical studies have confirmed that, in principle, market failure associated with technological innovation (e.g., Romer, 1990) can imply circumstances under which environmental regulations can lead to long-term benefits to industry (e.g., Ulph 1996; Simpson and Bradford 1996; Bovenberg and Smulders 1996; Xepapadeas and De Zeeuw 1999; Mohr, 2002).

Greaker (2003) assume that the environment is an inferior input in the production process due to the abatement technology. Environmental taxation is shown to increase competitiveness for some tax ranges. Imperfect competition plays important role in the theory. If the governments act strategically, but not for firms, firms can benefit from tighter environmental standards in the cost saving research (Ulph, 1996). Schmutzler (2001) investigates different incentives prevailing for firm managers who tend to be more risk averse than their owners. The regulation helps to re-align the preferences of principal and agent, and, therefore, increases the efficiency of the firm.

There are two paths that environmental policy can have effects on the productivity. The first path is direct effects on production. These direct effects include changes in inputs for the compliance of environmental regulation. This indicates that there are rooms for productivity improvements. We can test this path by analyzing the effect of the regulation on productivity. The second path is indirect effects. As Popp (2005) pointed out, if the regulations reduce uncertainty related to investments, more stringent environmental regulation may stimulate profitable R&D activity that may lead to new technological development. This new technological frontier, in turn, may improve productivity of firms. We can test this path by analyzing the effect of the regulation on R&D, and then test the effect of R&D on the productivity.

Several studies explored the second path through the relationship between environmental policy stringency and innovation activities using industry level data (see Jaffe and Palmer, 1997). The use of the industry level data suffers from the following problems. First, Porter and van der Linde (1995) used firm level case studies as examples for which the Porter Hypothesis holds. However, this may not be supported when numerous firms are aggregated to construct industry level data. Previous studies such as Jaffe and Palmer (1997) pointed out the difficulties in their research are due to the aggregated nature of data set and that the application of firm level micro data is necessary for further research. Even under the same environmental regulatory scheme, some firms successfully increase the productivities and some firms do not. Our study overcomes this problem using firm level micro data.

Another problem with these industry level studies is the use of pollution abetment expenditure（PACE）as a stringency of environmental regulation. The PACE is only an indirect measure of policy strength and does not necessary increase as the regulation become more stringent (Jaffe and Palmer, 1997). Consequently, they found mixed results on the Porter hypothesis.

In contrast, Berman and Bui (2001) successfully used unique a concrete measurement of policy stringency by focusing on oil refineries in US. They examined the first path: the direct effects of environmental regulation on productivity. They found that heavily regulated refineries in Los Angel’s area experienced productivity growth while less regulated refineries in other regions faced reduction in productivity in the same period. Our study follows their strategy to use a direct measurement of policy stringency by focusing exhaust gas emission standard.

In addition, estimating productivity is also crucial. For example, Managi et al. (2005) examined the first path by examining the effects of environmental policy on total factor productivity (TFP). Following recent literature measuring TFP as an index of productivity, we measure TFP to examine the first path.

In this study, we empirically explore how the environmental regulation affects firm’s productivity and R&D in the Japanese auto industry and whether the Porter hypothesis holds using panel data. The auto industry is chosen because the automobiles are known for its high environmental impacts. Moreover, the industry is known for larger extensive R&D activities. Finally, Japanese auto industry is known to have comparative advantage in environmental technology[1].

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[1] For detailed industry information, see Fujimoto and Takeishi (2001). See also Porter and Sakakibara

We apply exhaust emission regulation as the environmental regulation[2,3]. Even though the air quality in Tokyo has dramatically improved in 1980's, several problems still remain. Especially, metropolitan areas such as Tokyo or Osaka have not met the ambient air quality standard of nitrogen oxides ($NO_x$) and particulate matter (PM) set by Japanese Ministry of Environment until recently. Consequently, the tighter emission standards were introduced from 1990's to early 2000s. Therefore, the exhaust emission regulation is the appropriate policy to be scrutinized on its effects on productivity.

The purpose of this paper is twofold. First, this study explores the determinants of R&D and especially how the regulation affects the productivity through R&D expenditures. However, R&D expenditures are costs and not necessarily supporting Porter hypothesis itself although they may have the potential in the future. Thus, we consider the path that, if the environmental regulation simulates R&D expenditures, it may have effects on the productivity as well. Second, this study analyzes how the exhaust emission control standard directly affects the productivity of the firm, that is, to examine the Porter hypothesis.

The following section illustrates the situation of the auto industry and of the exhaust emission regulation. In section 3, model and data set are presented. Section 4 discusses the estimation results. Section 5 provides conclusion with possible extension.

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(2004) for industry structure in Japan.

[2] Top runner policy was expected to increase energy efficiency (sales divided by energy use) in Japan. However, Managi (2009) shows the policy encourage more capital cost and no statistically significant effect on the TFP in industries. Therefore, we do not control the policy effect in this study.

[3] Jaffe and Palmer (1997) provided several different interpretations of the Porter hypothesis. In the narrow version of the Porter hypothesis, the regulation focused on outcomes stimulates innovation than the regulation on process. The exhaust emission regulation is based on emission, which is outcomes rather than process. Thus, this study indirectly examines the narrow version of Porter Hypothesis.

## 2. Background

### 2.1 Empirical literature on Porter hypothesis

Previous studies find mixed results on the Porter hypothesis. There are cases supporting partial arguments of Porter hypothesis. This includes studies providing positive effects on R&D (e.g., Jaffe and Palmer, 1997) and cases of enhanced productivity (e.g., Berman and Bui, 2001). No support for productivity gain also found (e.g., Managi et al., 2005) and cost reduction effect but not offsetting regulatory cost is also found (Isaksson, 2005).

Jaffe and Palmer (1997) study industry level panel data of manufacturing industries and find a positive effect of compliance cost variable on R&D but an insignificantly negative impact on patenting. Berman and Bui (2001) study petroleum refineries at the US South coast and find productivity gains compared to other areas with less environmental regulation. They point out the other areas do not adopt new technologies because of uncertainty about cost and efficiency of the technologies and future environmental regulation.

Isaksson (2005) estimates abatement cost functions for reduction of nitrogen oxide emissions from energy production in three industrial sectors. She finds extensive emission reduction was been possible by low costs. Managi et al. (2005) study the productivity in Gulf of Mexico offshore oil and gas industry. They find no evidence for the standard formulation of the Porter hypothesis. Instead, they support the recast version of Porter hypothesis, which examines productivity of joint production of market and environmental outputs.

### 2.2 R&D of the auto industry

The auto industry performs extensive R&D activities. We select the Japanese auto industry since it is well-known for its advances in environmental technologies. According to the *Report on the Survey of Research and Development*, the Japanese auto industry spent more than

1 trillion yen in the fiscal year 2002 on research and development, which is 14.5% of total R&D expenditure spent by all industries. The auto industry had the largest R&D expenditure next to information and communication electronics equipment industry.

Significant amount of R&D is spent on environmental conservation. For example, its share is next to life science and it is followed by nanotechnology and information technology (see *The Survey of Research and Development* by Statistical Bureau, 2002). Approximately 500 billion yen was spent on environmental conservation, which is approximately 5% of total R&D expenditure spent by all industries. Figure 1 shows the expenses spent on environmental conservation by industry.

The auto industry shows the highest environmental conservation research expenditure, which makes up 40% of total environmental conservation research expenditure spent by all industries. In addition, about 12% of R&D expenditure is towards the environmental related technologies. Therefore, the auto industry compared to other industries has spent a great deal of effort in environmental protection.

The structure of the Japanese auto industry needs to be explored. The auto industry consists of two sub sectors, assembling firms and body/part firms. Assembling firms include Toyota or Honda who sell vehicles as their products. Body firms deal with body as their final products while parts makers are sellers of auto parts to assembling firms. The regulation is specifically targeted to assembling firms because they sell the final product to consumers who drive on the road. In addition to the assembling firms, we also include body/parts firms in our analysis because some of the industry innovation takes places in response to environmental regulation targeted to final product. That is, regulations add pressure not only on the firms that are subject to regulations (i.e, assembling firms), but also through the whole chain from suppliers of material and equipment (i.e, body/parts firms). This is important argument to support Porter hypothesis (see Porter and van der Linde, 1995).

This process is likely to exist because of the market power in 9 assembling firms. Though there are 66 body/parts firms, sales and R&D of assembling firms is more than twice of body/parts firms. The non competitive market structure in assembling industry is one reason why Porter hypothesis is empirically more likely to be observed because X-inefficiency might exist (see Roediger-Schluga, 2003).

### 2.3 Trend of emission control standards

Regulation of emission gases applied to automobiles began in 1966, where only the concentration of carbon monoxide (CO) was regulated. In 1978, hydrocarbon (HC) and nitrogen oxides ($NO_X$) also became subject to regulation by the Japanese version of the Muskie Law. Up to this point, the main target of the regulation was gasoline-engine vehicles. Diesel engine vehicles were either exempted from the regulation or faced weak regulation.

Despite these regulations, the standards of the “Total pollutant load controls” were not met for NOx by 1985. Thereafter, the regulation on $NO_X$ became more stringent. In 1997, in addition to the three substances (CO, HC, and $NO_X$), a new regulation was introduced to control particulate matter (PM) from diesel engine vehicles. With regards to motorbikes, the same type of regulation was initiated in 1998.

With regard to the annual level of motor vehicle exhaust emission standards, Figure 2 shows the annual level of motor vehicle exhaust emission standards from 1989 to 2002. The level of the standard, depends on the type of automobile, is adjusted to unity for each type of automobile for 1989. Annual value for each year is calculated by summing the relative value for each type of automobile. As in Figure 2, the standard is increasing annually. This is because the regulations on automobiles become more stringent over time and the extent of regulation to automobiles is expanding.

## 2.4 Regulatory Stringency

One innovation of this study is to construct direct measurement of environmental policy stringency using environmental emission standard. We construct the regulatory stringency variable, $reg_{i,t}$, which the assembling firm i faces in the year t, using information on emission standard for each pollutant (CO, HC, $NO_X$ and PM) set for each vehicle type k. Emission standard for pollutant p applied to vehicle type k in the year t[4] is defined as $E_{p,k,t}$ grams per km. We normalize the emission standard by using the emission standard for diesel trucks in announced in 1996, which is defined as the regulation intensity. It is expressed as

$$regulation_{p,k,t} = E_{p,k,t} / E_{p,\hat{K},1996}$$

where $\hat{K}$ represents the diesel truck and T=1996. Figure 3 illustrates the transition of the regulatory intensity for each pollutant after the normalization.

Using this regulatory intensity for each vehicle type, we construct the regulatory stringency variable for the firm i as follows:

$$reg_{i,t} = \sum_{p}\sum_{k} regulation_{p,k,t} \times share_{i,k,t} \qquad (1)$$

where $share_{i,k,t}$ is the ratio of type $k$ motor vehicle produced within the assembling firm i to

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[4] It should be noted that we used the information of notice of change in regulation by the government instead of information on date of enforcement of changed regulation, since a firm is more likely to respond to notice of change in regulation,

the total number of motor vehicle produced within each firm in the year t. We construct the regulatory stringency defined in (1) for the assembling firms. Therefore, each firm face different level of regulation stringency based on what they sell, and that is why we are able to control difference in stringency even the same year.

Concerning regulatory stringency for firms which manufacture vehicle bodies and parts, we use information on contract relationship between assembling firms and the others. They do not explicitly face the regulation but are likely to be affected indirectly through business relationship with the assembling firms for which they produce bodies and parts. Thus, we construct the regulatory stringency variable for these firms based on which assembling firms they cooperate with. In other words, firms that manufacture vehicle body and parts are influenced in the same manner as the assembling firm they cooperate with. Therefore, we apply the same regulatory stringency for the assembling firm to the firms manufacturing vehicle body and parts for it. For firms which cooperate with more than two assembling firms, the average of the emission stringency was taken. Likewise, when the firms manufacturing vehicle body and parts did not cooperate with specific assembling firms, the average of the entire assembling firms is used. Figure 4 shows the transition of the regulatory stringency at average for all firms.

## 3 Model and Data

### 3.1 Determinants of R&D expenditure

As the first step, we empirically analyze the effects of exhaust emission regulation on the firm’s R&D activities. This study considers two types of factors as determinants of R&D expenditure. The first factor concerns with the expected profit of R&D investment. The second factor is the financial aspect. Our formulization is as follows.

$$RE_{it} = \alpha_0 + \alpha_1 K_{it} + \alpha_2 CF_{it-1} + \alpha_3 S_{it-1} + \alpha_4 B_{it-1} + \gamma_1 REG_{it} + \gamma_2 REG_{it} ID_A + u_{it} \qquad (2)$$

where $u_{it}$ is an error term and the definition of the variables is summarized in Table 1. The effects of regulations on R&D investment depend on whether they are assembling firms or parts/body manufacturing firms. In order to capture this effect, we use the cross term of REG with $ID_A$. The regulation is directly applied to the assembling firms and, therefore, we expect larger effect from the regulations on the assembling firms.

### 3.2 Determinants of Productivity

(Productivity measure)

There are several techniques proposed in the literature of productivity (e.g., Olley and Pakes, 1996; Kumar and Russell, 2002). In this study, we apply deterministic frontier analysis, also known as data envelopment analysis (DEA). It is now common to measure the productivity especially when inefficiency of firms is important to consider. For example, inefficiency in input usage or output production became crucial in measuring productivity change (Caves, Christensen, and Diewert, 1982). Though productivity analysis is well established, traditional approaches, such as econometrics, growth accounting and index number methods, should be treated with caution. This is because they have major limitations including: (1) all decision-making units are assumed to be efficient; (2) data on costs, input prices and output prices are required. We use the mathematical programming technique of DEA to compute in TFP. A main advantage of this approach is that it is suitable to describe multi-input, multi-output production technology without having to specify functional forms[5]. In our study, we measure

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[5] DEA has strengths and weakness as in other techniques. The measurement error, missing variables, and

Luenberger productivity indicator to capture the productivity. (See Appendix for the detailed explanation on the indicator.)

(Model of Productivity)

Research and development activities of firms are constructed by the accumulation of R&D expenditure flow. If economic growth depends on technological innovation rates and technological innovation rates depends on the accumulation of R&D activities, the R&D stock within the firm, which is the aggregate of R&D expenditure (flow), becomes important in the firms' production activities. We estimate the relationship between R&D expenditures and productivity change.

The model to examine the effects of environmental regulations on productivity is expressed in equation (5). The cross term of the change in regulation and R&D productivity is added to test whether the stricter regulation weakens the effect of the R&D on the productivity.

$$\frac{TFP_{k,t}-TFP_{k,t-1}}{TFP_{k,t-1}}=\lambda+\sigma_1\left(\frac{REG_{k,t}-REG_{k,t-1}}{REG_{k,t-1}}\right)+\sigma_2\left(\frac{REG_{k,t}-REG_{k,t-1}}{REG_{k,t-1}}\right)*ID_a$$

$$+\rho_1\left(\frac{RE_{k,t-1}}{Q_{k,t-1}}\right)+\rho_2\left(\frac{REG_{k,t}-REG_{k,t-1}}{REG_{k,t-1}}\right)\left(\frac{RE_{k,t-1}}{Q_{k,t-1}}\right)+a_k+u_{k,t} \tag{3}$$

where $a_k$ indicates the unobserved effect with mean zero for a random effect model and fixed for a fixed effect model, and $u_{it}$ is an error term. Here again we consider both of direct and indirect

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unmeasured quality differences can cause problems because DEA is a data-driven technique. Analogous problems exist for econometrics and other empirical techniques. Confidence intervals and statistical hypothesis tests are difficult to implement within DEA.

effects of regulations. The value of *RE* is predicted value from the results of R&D model (equation (2))

### 3.3 Data

We construct the twelve-year panel data of 75 firms from 1990 to 2002 that belong to the auto industry defined by *Nikkei Needs Database*. Firm characteristics are collected from "Nikkei financial data" in *Nikkei Needs Database*. The regulation values are measured values using from the Ministry of the Environment (http://www.env.go.jp/). The descriptive statistics are shown in Table 2.

We note that the minimum value of the regulation is zero. This is because no regulation was applied to several firms producing motorbikes before 1998. With regards to R&D expenditure, the mean and the standard deviation are 3,170 and 27,500 million yen, respectively, while the minimum and the maximum are zero and 486,000 million yen, respectively. We find that R&D varies widely. The size of the firm measured by sales also varies largely from 4,060 to 9,520,000 million yen. With regards to the cash flow, several firms have negative cash flow reflecting the long recession in Japan.

## 4. Results

### 4.1 Determinants of R&D expenditure

To analyze the effects of the motor vehicle exhaust gas emission regulation on the R&D, we estimate equation (2) as the base model. We apply fix effect model, random effect model, and dynamic Tobit model (see Arellano, Bover, and Labeaga, 2010). Table 3-1 and Table 3-2 provide results of dynamic Tobit model and fix effect model, respectively. Table 3-2 only shows fix effect model because of the choice by Houseman test. We apply dynamic Tobit model to equation (2) because several companies have zero for R&D expenditure in some years. We used 75 firm's panel data from 1989 to 2002 for estimation. Total number of the observation is 1028 after eliminating 22 samples with missing values.

(Insert Table 3-1 and 3-2)

The parameter on regulation is significant with positive sign in dynamic Tobit model while it is not in fix effect model. The parameter on the cross term of the regulation with dummy for assembling firms is significant with the positive sign in all cases. These indicate that the stronger regulation is likely to encourage the R&D activity of the assembling firms as well as the parts manufacturing firms and body manufacturing firms. However, the effects on the assembling firms are likely to be larger than that on the parts or boy manufacturing firms. The latter finding is considered to result from the fact that the regulation is directly applied to the assembling firms.

Concerning the other variables, the sign of several parameters are as expected, while the others are not. The parameter on capital stock, K, is statistically significant with the positive sign in the fixed effect model as expected, but not in dynamic Tobit model. This indicates that the large size company is likely to have more R&D expenditure. The parameters for cash flow, a proxy for financial state, are significant with positive sign in all models. This result in the fixed effect model implies that firms with a larger cash flow are likely to be capable of conducting R&D activities because such firms can bear the higher risk of the R&D failure. The other financial variable, debt, was statistically insignificant in dynamic Tobit model and significant and positive in fix effect model, contrary to the expectation. The Sales, the proxy for expected demand, was significant with negative sign in most of the cases.

## 4.2 The Productivity Analysis

In this section, we discuss the two-step approach to analyze productivity in the auto industry. In the first step, productivity is measured by using Luenberger productivity indicator. In the second step, we investigate the determinants of productivity change by using an econometric model.

First, we measure productivity changes in the auto industry. Separate frontiers are estimated for each year, and shifts in the frontiers over time are used to measure productivity changes. For each firm, we use the arithmetic mean of the productivity indicators to obtain a combined value for each indicator in each year (see Balk, 1998). The arithmetic mean value of their indicator is 0.012. Values larger than zero represent increases in productivity and therefore the auto industry shows productivity increase on average.

Second, we estimate equation (3) using 75 firm’s panel data from 1990 to 1999 for estimation. The total number of the sample is 738 after eliminating 12 samples with missing values. Estimation results are shown below in Table 4-1 and 4-2. The fixed effect model was selected by the Hausman test.

(Insert Table 4-1 and 4-2)

Table 4-1 shows that both the coefficient for the regulation and the coefficient for the cross term of the change of the regulation level with the dummy variable for the assembling firms were insignificant for the fixed effect model. This indicates that as a direct effect of environmental regulation on the productivity of assembling firms, the stricter regulation does not affect neither the productivity of the assembling firms nor the productivity of the parts manufacturing and the body manufacturing firms. Thus, this result does not support the Porter Hypothesis.

With regards to the effect of R&D on the productivity, the coefficient for the R&D was significantly positive. This indicates that the increase in R&D induces higher productivity. From this estimate, the marginal productivity of R&D is calculated as 0.27. This number is close to the estimate of Goto and Suzuki (1989), which analyzed the effect of the R&D of the Japanese manufacturing firms on their productivity.

Arimura and Sugino (2008) found that the stringent environmental regulation increases the ratio of environmental R&D to general R&D expenditures using Japanese manufacturing data. As such, the environmental regulation may crowd out some production R&D expenditure, which contributes to higher productivity consequently, by increasing the share of environmental R&D devoted for environmental purposes. However, it should be noted that the coefficient for the cross term of the regulation and R&D on productivity was insignificant. This indicates that the stricter regulation does not reduce the effect of increase in R&D on the productivity. It was expected that the increase in R&D expenditure due to the stricter regulation contributed to the improvement of the environmental performance of the automobile but no or less increase in the productivity of the firm. Increase in R&D due to the stricter regulation may be spent on the improvement of the fuel saving to reduce pollutant concentration as well as that of the environmental performance of the automobile and thus the positive effect on the fuel saving may offset the negative effect on the productivity.

## 5. Conclusion

We empirically analyze environmental regulation on the firm level R&D expenditure and productivity in the Japanese auto industry. We find exhaust emission regulation stimulates R&D expenditure of the firm in the auto industry. Especially, the effect of the regulation on R&D expenditure of the assembling firms is larger than that of the parts manufacturing and the body manufacturing firms. The reason behind this finding may be due to the fact that the regulation is directly applied to the assembling firms. We also find that increase in R&D raises the productivity of the firms, while the stricter regulation does not reduce the effect of R&D on productivity. On the other hand, the regulation does not directly raise the productivity in the auto industry. This indicates that the Porter Hypothesis is not supported. Thus, the stronger regulation is likely to increase the productivity indirectly, i.e. through the increase in R&D activity, though the Porter Hypothesis is not supported.

The analysis of the Japanese auto industry did not support the Porter Hypothesis.. However, this requires further analysis. When the exhaust emission standards become more stringent, firms have to produce new automobiles that comply with the new regulation. If a firm is successful in inventing these new automobiles, the firm will obtain a larger share than before. This will have effects on the consumer side of the auto markets. A structural approach that incorporates consumer’s behavior in analysis will clarify the impact on the demand side. Furthermore, it is not clear if the result on productivity holds for other industries. It is desirable to expand this analysis to other industries by applying firm level micro data considering both direct and indirect effects. These will be an important extension of this study.

Kerr and Newell (2003) explored the relation between the policy instruments and the incentive of the US refineries to adopt the pollution abatement technology using the panel data. They found that new technology is implanted as the stringency of regulation increases and that economic instruments for environmental protection lead to the more cost-effective adoption of new technology than the non-market based instruments as the theory suggested (Malueg (1989) for example). It is interesting to see if different environmental policy instruments lead to different effects on productivity. This is another area of future research.

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Appendix: Productivity measure

There are two indices to measure the productivity, the Malmquist Index and Luenberger productivity indicator. The Malmquist Index is either based upon Shephardian input- or output distance function compatible with the objectives of cost minimization or revenue maximization (Färe and Primont, 1995). In contrast, we apply more generalized productivity measurement methodologies (called Luenberger productivity indicator) than the Malmquist Index. This is because it might be preferable to assume profit maximization, which is the traditional assumption in economic theory. In this study, we apply Luenberger productivity measurement, where the productivity is based on profit maximization (Chambers and Pope, 1996).

We measure the productivity indicator employing a proportional distance function and allows for inefficiency in each decision-making unit as firm. Using the proportional distance function specification, our problem can be formulated as follows. Let $x = (x^1,...,x^N) \in \boldsymbol{R}^N_+$ and $y = (y^1,...,y^M) \in \boldsymbol{R}^M_+$ be the vectors of inputs and output, respectively, and define the technology set by $P_t \equiv \{(x_t, y_t)$: $x_t$ can produce $y_t\}$. The technology set, $P_t$, consists of all feasible input vectors, $x_t$, and output vectors, $y_t$, at time period $t$ and satisfies certain axioms, which are sufficient to define meaningful proportional distance functions. The measurement of efficiency relative to production frontiers relies on the theory of distance functions[6]. Luenberger (1992) generalizes the previous notion of distance functions and provides a flexible tool to integrate both input contractions and output improvements when measuring efficiency. This directional distance function is the dual to the profit function (Chambers, Chung, and Färe, 1998).

We define the directional distance function at $t$ as:

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[6] The distance functions are related to the notion of the coefficient of resource utilization (Debreu, 1951) and to efficiency measures (Farrell, 1957).

$$D^t\left(\mathrm{x_t},\mathrm{y_t}\right) = \max\left\{\delta : ((1-\delta)\mathrm{x_t},(1+\delta)\mathrm{y_t}) \in P_t\right\}$$

where $\delta$ is the maximal proportional amount by which output, $y_t$, can be expanded and input, $x_t$, can be reduced simultaneously given the technology, $P^t$. The DEA formulation calculates the productivity indicator under variable returns-to-scale (VRS) by solving the following optimization problem:

$$\begin{aligned} &D^t(\mathrm{x_t},\mathrm{y_t}) = \max_{\delta,\lambda}\delta \\ &s.t. \quad Y_t\lambda \geq (1+\delta)\,y_t^i \\ &\qquad\;\; X_t\lambda \leq (1-\delta)\,x_t^i \\ &\qquad\;\; N1'\lambda = 0 \\ &\qquad\;\; \lambda \geq 0 \end{aligned}$$

where $\delta$ is the efficiency index for firm *i* in year *t*, *N1* is an identity matrix, $\lambda$ is an N×1 vector of weights which is the proportionality factor and same for both of inputs and output, and $Y_t$ and $X_t$ are the vectors of output, $y_t$, and inputs, $x_t$. To estimate productivity change over time, several proportional distance functions, including both single-period and mixed-period distance functions for each firm and each time period, are needed. For the mixed-period distance function, we have two years, *t* and *t+1*. For example, $D^t(x_{t+1}, y_{t+1})$ is the value of the proportional distance function for the input–output vector for period *t+1* and technology in period *t*. Several proportional distance functions are needed to mesure the change in productivity over time as for Luenberger productivity indicators.

Figure 1. R&D expenditure in Japan (100 million yen)

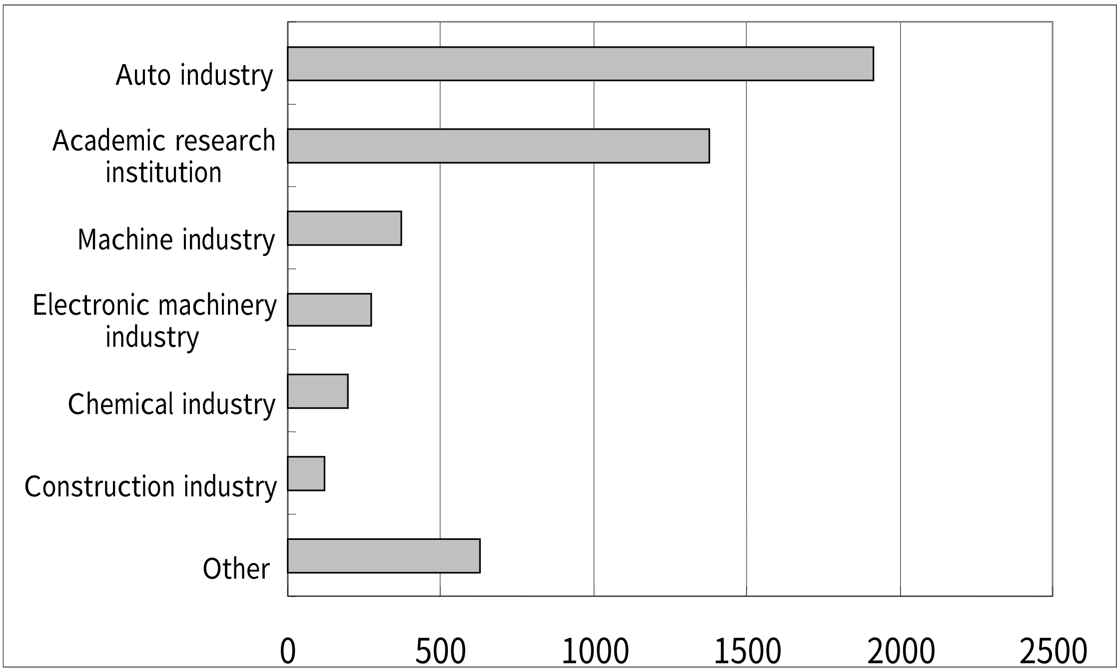

Figure 2. Motor Vehicle Exhaust Emission Standards in Japan

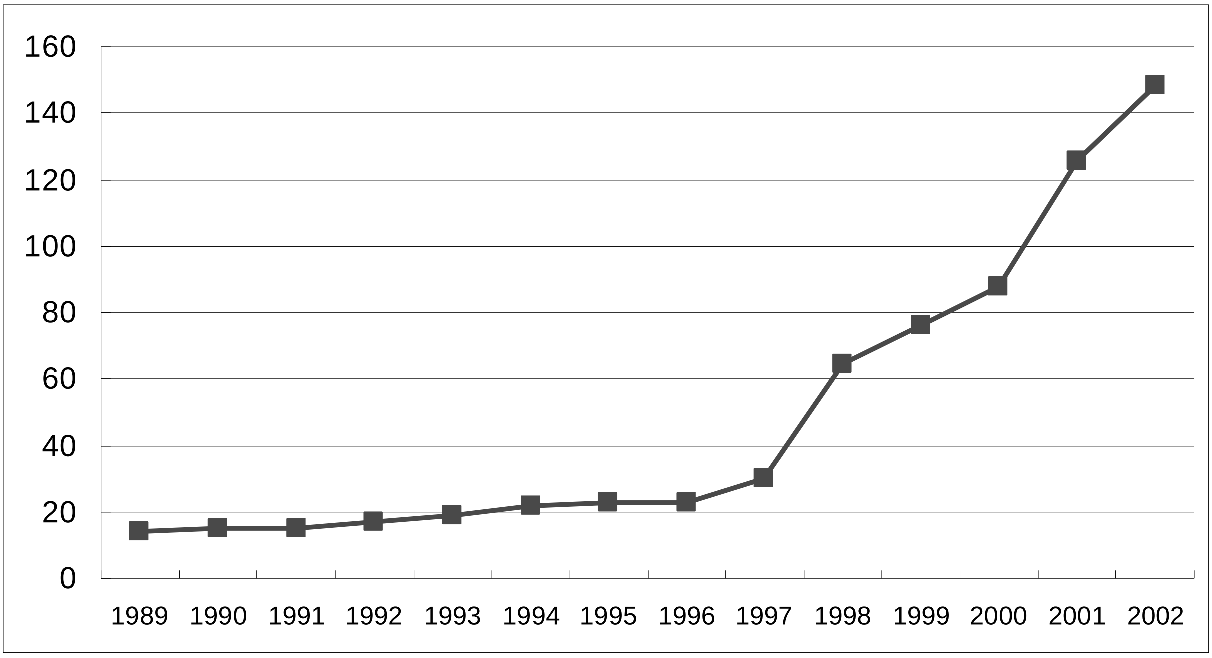

Figure 3. Regulatory Intensity for each pollutant

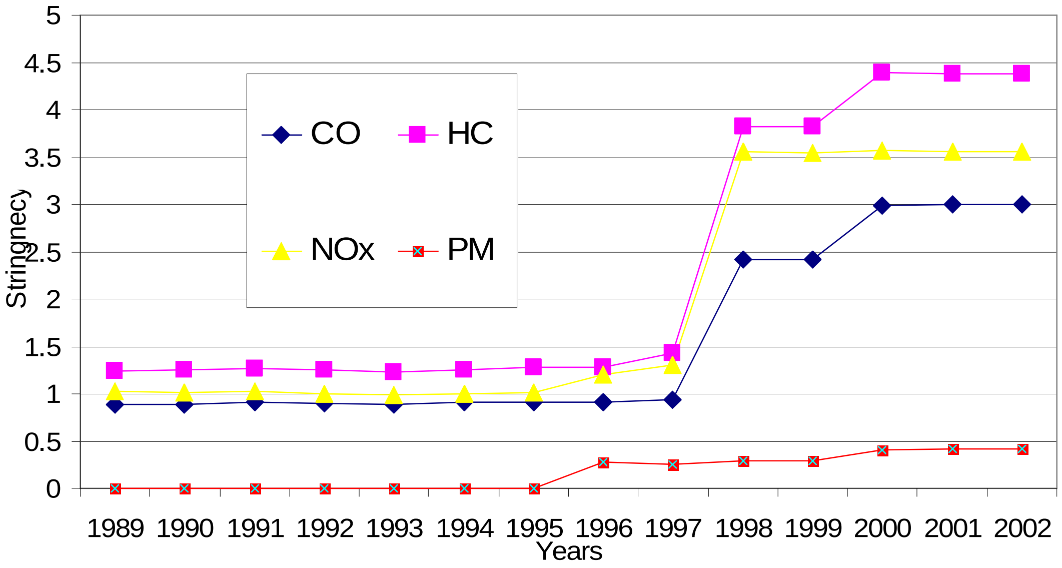

Figure 4. Aggregated Regulatory Intensity

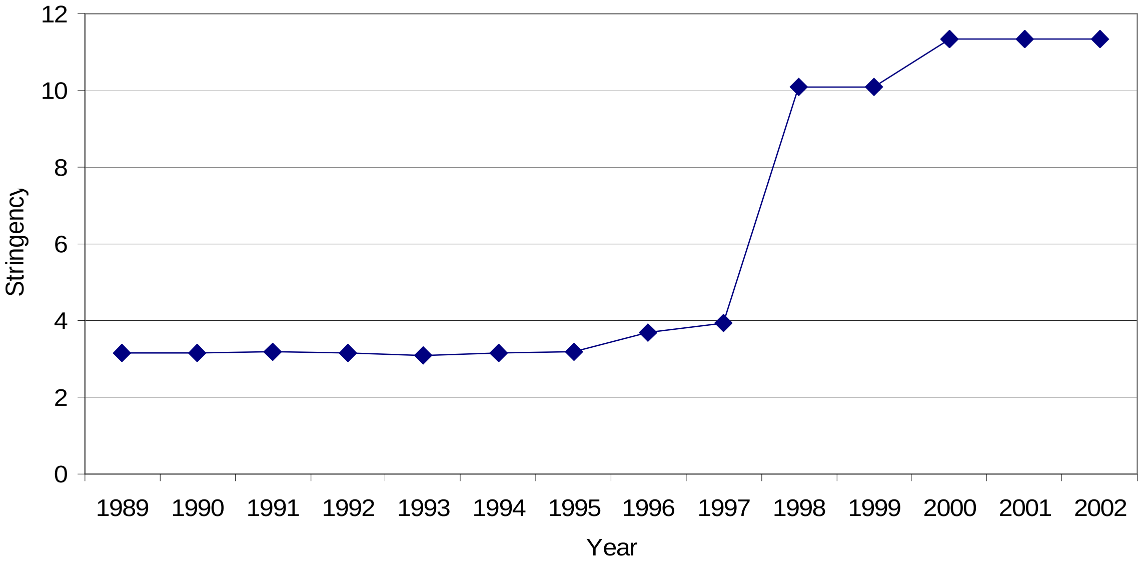

Table 1. Definitions of the Variables

| Variable | Name | Definition |
|---|---|---|
| RE | Annual R&D Expenditure | Annual R&D expenditure |
| K | Capital Stock | Tangible Fixed Asset |
| CF | Cash Flow | Cash flow divided by the tangible asset |
| B | Debt | Debt divided by the tangible asset |
| S | Sales | Annual Sales divided by the tangible asset |
| $ID_A$ | Dummy for Assembling Firms | $ID_A$=1, if the firm is a assembling firm, $ID_A$=0, otherwise |
| REG | Level of Regulation | - |
| Q | Output | Value added |

Table 2. Descriptive Statistics

|  | unit | Observations | Mean | Standard Dev. | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Output(Value added) | Million yen | 1028 | 130,000 | 361,000 | 2,090 | 3,440,000 |
| R&D expenditure | Million yen | 1028 | 3,170 | 27,500 | 0 | 486,000 |
| Capital Stock | Million yen | 1028 | 82,200 | 203,000 | 1,510 | 1,810,000 |
| Debt | Million yen | 1028 | 150,000 | 390,000 | 1,470 | 3,120,000 |
| Sales | Million yen | 1028 | 379,000 | 1,120,000 | 4,060 | 9,520,000 |
| Cash Flow | Million yen | 1028 | 19,500 | 67,700 | -34,200 | 699,000 |
| Regulation | *** | 1028 | 6 | 3.76 | 1.99 | 12.9 |

Table 3-1. Estimation Results for R&D model (Dynamic Tobit Model)

| | Specification 1 | Specification 2 | Specification 3 |
|---|---|---|---|
| K | 0.093<br>(1.20) | - | - |
| CF | 1.213***<br>(8.02) | 1.155***<br>(8.05) | 1.177***<br>(8.24) |
| S | -0.053***<br>(-2.88) | -0.037***<br>(-2.92) | -0.039***<br>(-3.03) |
| B | -0.028<br>(-1.14) | -0.020<br>(-0.84) | -0.023<br>(-0.96) |
| REG | 2415.689**<br>(2.25) | 2331.493**<br>(2.17) | - |
| REG*$ID_A$ | 13491.290***<br>(4.75) | 14618.21***<br>(5.42) | 16017.77<br>(6.15) |
| Lagged R&D | 0.006<br>(1.09) | 0.010<br>(0.86) | 0.009<br>(1.03) |
| Constant | -16289.360***<br>(-3.21) | -15170.71***<br>(-3.04) | -6869.33<br>(-2.19) |
| Log likelihood | -6891.642 | -6884.5024 | -6886.870 |
| Sample size | 1028 | 1028 | 1028 |

The value in the parenthesis represents t-value. ***, **, and * indicates that the coefficient is significantly different from 0 at 1%, 5% and 10% respectively.

Table 3-2. Estimation Results for R&D model (Fixed Effect Model)

| | Specification 1 | Specification 2 | Specification 3 |
|---|---|---|---|
| K | 0.236***<br>(2.70) | - | - |
| CF | 1.419***<br>(9.65) | 1.272***<br>(9.26) | 1.272***<br>(9.26) |
| S | -0.044**<br>(-2.10) | -0.021<br>(-1.09) | -0.021<br>(-1.10) |
| B | 0.093**<br>(2.39) | 0.099**<br>(2.53) | 0.099**<br>(2.53) |
| REG | -295.704<br>(-0.30) | -211.136<br>(-0.21) | - |
| $REG*ID_A$ | 8780.082***<br>(2.70) | 10917.72***<br>(3.45) | 10725.57***<br>(3.54) |
| Constant | -32108.03***<br>(-3.80) | -21690.61***<br>(-2.87) | -22223.34***<br>(-3.12) |
| R-squared | 0.25 | 0.24 | 0.24 |
| Sample Size | 1028 | 1028 | 1028 |

The value in the parenthesis represents t-value. ***, **, and * indicates that the coefficient is significantly different from 0 at 1%, 5% and 10% respectively.

Table 4-1. Estimation Results for Productivity Analysis (Fixed effect model)

| | Specification 1 | Specification 2 | Specification 3 |
|---|---|---|---|
| $\Delta$REG | -0.008<br>(-0.75) | -0.006<br>(-0.61) | -0.007<br>(-0.66) |
| $\Delta$REG*ID$_A$ | 0.014<br>(0.50) | - | 0.015<br>(0.53) |
| (RE/Value Added)*$\Delta$REG | 0.011<br>(0.47) | 0.011<br>(0.51) | - |
| RE/Value Added | 0.271**<br>(2.46) | 0.274**<br>(2.50) | 0.263**<br>(2.41) |
| Constant | -0.032<br>(-1.67) | -0.033<br>(-1.70) | -0.031<br>(-1.63) |
| Sample Size | 738 | 738 | 738 |

The value in the parenthesis represents t-value. ***, **, and * indicates that the coefficient is significantly different from 0 at 1%, 5% and 10% respectively.

Table 4-2. Estimation Results for Productivity Analysis (Random effect model)

| | Specification 1 | Specification 2 | Specification 3 |
|---|---|---|---|
| $\Delta$REG | -0.001<br>(-0.10) | 0.000<br>(0.02) | -0.001<br>(-0.08) |
| $\Delta$REG*ID$_a$ | 0.043*<br>(1.79) | - | 0.043*<br>(1.79) |
| (RE/Value Added)*$\Delta$REG | 0.001<br>(0.07) | 0.002<br>(0.07) | - |
| (RE/Value Added) | 0.019***<br>(3.32) | 0.019***<br>(3.33) | 0.019***<br>(3.48) |
| Constant | -0.010<br>(-0.76) | -0.011<br>(-0.77) | -0.011<br>(-0.78) |
| R-Squared | 0.02 | 0.02 | 0.02 |
| Sample Size | 738 | 738 | 738 |

The value in the parenthesis represents t-value. ***, **, and * indicates that the coefficient is significantly different from 0 at 1%, 5% and 10% respectively.