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and Productivity:
Evidence from Taiwan's Manufacturing Industries**

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Environmental Regulations, Induced R&D, and Productivity:
Evidence from Taiwan's Manufacturing Industries

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Abstract

This paper examines whether stringent environmental regulations induce more R&D and promote further productivity in Taiwan. Using an industry-level panel dataset for the 1997–2003 period, empirical results show that pollution abatement fees, a proxy for environmental regulations, is positively related to R&D expenditure, implying that stronger environment protection induces more R&D. On the other hand, pollution abatement capital expenditures do not have a statistically significant influence on R&D. Further evaluation of the influence of induced R&D by environment regulations on industrial productivity shows a significant positive association between them. This finding supports the Porter hypothesis that more stringent environmental regulations can lead to a possible “win-win” situation.

Keywords: Environmental regulations; R&D; productivity; Porter hypothesis

JEL classification: L60, O13, Q55, Q58

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1. Introduction

Along with economic development, the accompanied pollutions created by economic activities have seriously harmed global environment and further caused climate change. Coping with the challenges of climate change has become a crucial task for both scientists and economists. Despite economists trying to quantitatively assess the socioeconomic impacts of climate change, its potential damage appears to be far beyond our expectations. One of the possible solutions for this is to reduce the various kinds of pollution. The first Earth Day in 1970 marked the beginning of the modern environmental movement (Jaffe *et al.*, 1995). Since then, environmental issues have received increasing attention in most countries and have led to widely acknowledged concerns about the effects of different environmental policy measures.

Pollution is recognized as a public good with negative externality. Economic development generally leads to the overproduction of pollutants if there is no policy intervention. How do we reduce the emission level of industrial pollutants? The two widely adopted instruments are direct intervention through strict environmental regulations and a market-oriented approach through emission tax and pollution permit trade. While stringent environmental regulations can reduce industrial pollution immediately, they may retard economic growth owing to higher production costs (Jorgenson and Wilcoxon, 1990).¹ On the other hand, Porter and van der Linde (1995) claim that well-designed environmental policies can lead to improved competitiveness in firms by improving efficiency levels and encouraging innovations. This is the so-called Porter hypothesis: stringent environmental regulations can achieve a win-win situation in which an economy can simultaneously attain both goals of a cleaner environment and competitiveness. Therefore, technological change is one of the predominant factors for solving long-term environmental problems, and it serves as the prerequisite of supporting the Porter hypothesis argument.

¹ For a detailed discussion on market-based environmental policy instruments, see Stavins (2005).

If stringent environmental regulations are enforced, can we expect firms to develop new products and/or processes to cope with the regulations? The innovation effects of stringent regulations have attracted increased attention among economists, for example, Lanjouw and Mody (1996), Jaffe and Palmer (1997), Brunneheimer and Cohen (2003), de Vries and Withagen (2005), and Hamamoto (2006). While these studies in general reveal a significantly positive effect of increased stringency on innovations (R&D or patents), they focus on evidence from developed countries such as the U.S., Japan, and some OECD members. A relatively large number of studies have been conducted on another line of research that directly relates environmental regulation to competitiveness in terms of productivity to test the Porter hypothesis, but results have been inclusive results (see Brännlund and Tommy (2009) for a comprehensive review).

This study examines the R&D enhancement effects of stringent environmental regulations, its consequent indirect influence on productivity, and the direct relationship between regulatory stringency and productivity in Taiwan's manufacturing industries. It provides three distinct results that contribute to the empirical literature in this line. First, most studies testing the Porter hypothesis focus on the advanced economies that have been experiencing a flourishing manufacturing sector; only a few examine this issue from the point of newly industrialized economies (NIEs). Taiwan presents an excellent case for a review of this question. Taiwan's postwar economic miracle is by now a very familiar case in development economics literature, but her rapid development of manufacturing industries and lax environmental regulations lead to the deterioration of the environment. Realizing the importance of environmental protection for sustainable development after an era of rapid industrialization, Taiwan's government has, since the 1980s, devoted more attention to implementing environmental regulations. In the last two decades, Taiwan has been very successful in narrowing down the technological gap with its counterparts among the leading countries, especially in electronics technology. Taiwan's R&D/GDP

ratio rose from 1.62% in 1990 to 2.78% in 2008, and since 2003, the country has occupied the fourth position in the world in terms of quantity of U.S. patents.² Can the increasing innovations in Taiwan be partly attributed to the stringency of her environmental regulations? We examine whether the Porter hypothesis holds in the case of Taiwan and whether regulatory stringency leads to improved industrial competitiveness in terms of productivity, resulting in a win-win situation. This study adds new evidence to this line of research by providing data from NIEs.

Second, previous studies generally adopt productivity as a proxy for “competitiveness” to test the Porter hypothesis, which links environmental regulations to productivity. There are two opposing views on this relationship, resulting in an uncertain result a priori. A more stringent environmental regulation may push production costs up at first, but later, it may change the input combinations and consequently improve productivity. Linking regulatory stringency to productivity is a direct way to test the Porter hypothesis. Porter and van der Linde (1995) claim that improved competitiveness can be attributed to induced innovations. This implies that productivity can be enhanced through induced R&D brought about by environmental regulations. However, no studies, except Hamamoto (2006), examine the indirect productivity enhancement effects of induced R&D. More specifically, the productivity measure used by Hamamoto (2006) does not control for the endogenous choice of changing input combinations in response to stringent environmental regulations, leading to a biased estimate of the productivity effect of induced R&D. This study adopts the total factor productivity (TFP) approach developed by Levinsohn and Petrin (2003), which takes into account problems of endogeneity and unobservable heterogeneity in determining inputs. It enables us to clarify the real impact of induced R&D, if any, on industrial productivity.

Third, the measurement of environmental regulations is a crucial issue in this line of

² An international comparative study conducted by Trajtenberg (2001) shows that Taiwan ranked high in terms of patents per capita, compared with the G7 countries and the other “Asian Tigers.”

research. The “Pollution Abatement and Control Expenditures” (PACE), which reflects pollution abatement capital expenditures and operating costs, is adopted as the proxy variable in many existing studies, for example, Jaffe and Palmer (1997), Berman and Bui (2001), Brunnermeier and Cohen (2003), and Hamamoto (2006).³ However, owing to the availability of information, these studies adopt either abatement capital cost or abatement operating cost. Fortunately, our dataset includes detailed information about the expenditures of pollution abatement, which enables us to divide the total PACE into abatement capital and abatement fees. More specifically, data on abatement capital expenditure in individual pollution control, including wastewater, waste gas, wastes disposal pollution, and noise pollution, are also available. The detailed information helps us obtain insightful analyses and provide policy implications.

The remainder of this study is organized as follows. Section 2 briefly reviews the literature regarding the effect of environmental regulations on innovation and productivity. Section 3 introduces the development of environmental regulations and environment-friendly innovations in Taiwan. Section 4 proposes the empirical models and describes the dataset. Section 5 displays the empirical estimates and discusses the results. The final section contains concluding remarks and policy implications.

2. Literature Review

Numerous studies have tested the Porter hypothesis from various aspects, such as regulatory effects on innovations, productivity, investment, and profits. Some works, for example, Wagner (2003), Ambec and Barla (2006), and Brannlund and Lundgren (2009), have provided excellent and comprehensive evaluations. We now briefly review two lines of research that are directly related to this study, the environmental regulatory effects on innovations (R&D) and on productivity.

³ Although PACE is not a perfect candidate for measuring environmental stringency (Brannlund and Lundgren, 2009), it is considered acceptable owing to the lack of data and the difficulty of defining the strength of environmental regulations.

2.1 Environmental regulations and R&D activities

Theoretical literature on environmental regulations and R&D can be traced back to the early 1970s (e.g., Zerbe, 1970), while empirical studies emerged only in the mid-1990s and remained limited. Lanjouw and Mody (1996) present the first evidence on environmental innovation and diffusion over the 1970s and 1980s, when public awareness and concern about environmental damage began to rapidly increase. Using national R&D expenditure data and patents, their analysis finds that increasing interest in environmental protection led to the development of new pollution control technologies. Jaffe and Palmer (1997) examine whether increased stringency of environmental regulations would spur firms to increased innovative activities, using a panel dataset of U.S. manufacturing industries over the 1973–1991 period. Although the industry-level analysis overall gives mixed results, they find a significant positive relationship between regulatory compliance expenditures and the regulated industry's R&D expenditures after controlling for industry-specific effects. This suggests that stricter environment regulations significantly induce R&D expenditures in the U.S manufacturing industries.

Using PACE on capital and R&D as the proxy variables of environmental regulation strength and innovative activity, respectively, Hamamoto (2006) examines the potential R&D inducement effect of stringent environmental regulations in Japan during her rapid industrialization period of 1960–1970. The industry-level study finds that the capital cost of pollution control has a positive relationship with R&D expenditures, supporting the view that environmental regulations based on a command and control approach could trigger off R&D activities in the Japanese manufacturing industries.

Supported by the surveyed firm-level dataset of seven OECD countries,⁴ parallel but independent studies by Arimura *et al.* (2007), Frondel *et al.* (2007), and Lanoie *et al.* (2007) employ microeconomic techniques to analyze the stimulated effects of stringent

⁴ This survey is under an OECD project on Public Environmental Policy and The Private Firm covering seven OECD countries, including Canada, France, Germany, Hungary, Japan, Norway, and the United States.

environmental policies on environmental R&D performance. Their empirical results show that strict environmental policies, measured by the perceived policy stringency of the firms in question, environmental accounting systems, and flexible environmental instruments, stimulate environmental R&D. This suggests that a stringent policy plays the role of an essential driving force to foster R&D.⁵

2.2 *Environmental regulations and productivity*

The other line of research, using productivity as the measure of competitiveness to test the Porter hypothesis, has a relatively long history, resulting in a larger number of studies and displaying different results. Some selected recent studies are reviewed below.

Lanoie *et al.* (2001) examine whether a stringent environmental regulation stimulates industrial productivity in Canada. In their study, environmental regulation and productivity are measured by the change in the ratio of the value of investment in pollution-control equipment to the total cost and the Törnqvist index, respectively. Empirical findings suggest that a stringent environmental regulation leads to a significant positive influence on productivity growth. Berman and Bui (2001) show that refineries in Los Angeles faced with stricter air quality regulations experience higher productivity than refineries in other U.S. regions. Despite a higher abatement cost brought about by stricter environmental regulations, the pollution control investment by Los Angeles refineries turns out to enhance their productivity, supporting the Porter hypothesis.

Using the Data Envelopment Analysis (DEA) approach, Managi *et al.* (2005) decompose TFP growth into market outputs (oil production and gas production), environmental outputs (water pollution and oil spill), and joint production to evaluate the sources of the various components of TFP growth. Using data from the Gulf of Mexico offshore oil and gas industry during the 1968–1995 period, the empirical estimates indicate that higher costs of complying with environmental regulations would enhance the

⁵ The line of study using patents or environmental innovations as indicator of innovations is not reviewed here; such studies include Brunneimer and Cohen (2003), De Vires and Withagen (2005), Rehfeld *et al.* (2006), and Horbach (2008).

productivity of both environmental and market outputs. Hamamoto (2006) uses an indirect approach to examine the effect of environmental regulations on productivity growth in Japanese manufacturing industries. The findings support the view that environmental regulations have a positive influence on productivity improvements, via positive R&D effects.

On the other hand, Barbera and McConnell (1990) separate the productivity effects of environmental regulations into direct (abatement costs) and indirect effects (via other inputs and production). Estimating the cost function for five American emission-intensive industries, they find a decline (10%–50%) in productivity in every sector following more stringent abatement requirements. The indirect effects also contribute to an overall production decline. Taking the plant vintage and technology differences into account, Gray and Shadbegun (2003) find that U.S. pulp and paper mills with higher pollution abatement operating costs have significantly lower productivity levels, especially in integrated paper mills. This suggests a strong significant negative effect of environmental regulations on productivity.

Reviewing the literature, more stringent environmental regulations seem to spur more R&D, but with an uncertain impact on productivity. In fact, two points are worth examining with regard to the environmental regulation-productivity nexus. One is the direct and indirect effects mentioned in Barbera and McConnell (1990). Specifically, the indirect effects brought about by induced R&D have not been adequately examined, with the exception of Hamamoto (2006). In evaluating the indirect productivity effects brought about by induced R&D, the TFP measure developed by Levinsohn and Petrin (2003) serves as a more satisfactory indicator. The other is the measure of the stringency of environmental regulations. As the literature uses PACE on either capital or operating fees, more detailed information on PACE would help obtain robust results.

3. Development of Environmental Regulations and Innovations in Taiwan

The manufacturing sector emerged as the primary contributor of employment and economic growth in Taiwan since her economic take-off in the late 1960s. In the mid-1970s, Taiwan's industrial structure transformed from being labor-intensive industries to capital-intensive and energy-consuming industries such as metal, petrochemical, synthetic fiber, and electronics industries. Owing to lax environmental regulations, this resulted in a rapid increase in the emission of various pollutants, worsening the quality of the environment. Along with people's environmental awareness increased, debate on the relationship between economic growth and environmental quality emerged in the late 1970s (Shaw, 1994). To echo the emerging public concern for environmental protection and to achieve sustainable development, the government initially enacted two major environment statutes, the Water Pollution Control Act and the Waste Disposal Act, in 1974. The Air Pollution Control Act came into effect the following year. By 1983, when the Noise Control Act was legislated, the environmental statutes seemed to be complete in Taiwan.

However, law is one thing and enforcement another. Firms, developers, and others with incentives to avoid environmental regulations are typically well-organized economic units, with large stakes in the enforcement of stronger environmental protection legislation. Owing to information asymmetry, firms tend to hide emission information, shirking environmental supervision. Furthermore, some firms may even bribe or threaten the team in charge of environmental supervision, lowering the effectiveness of environmental statutes. In fact, each of the aforementioned environmental statutes has so far been revised only slightly, maybe once or perhaps not at all in the 1980s. One possible reason could be that economic growth remained the primary national target for Taiwan in the 1980s. Importantly, the RCA pollution event that was disclosed in 1988 shocked the Taiwanese

society.⁶ Mon (2002) argues that this event can be attributed to the failure of government regulations, lack of corporate self-regulation, lack of public concern about corporate crime, corporate mechanistic structure, and the low self-control tendency of corporate managers. This event deeply awakened the environmental awareness of both the public and the government. As a result, the government began to implement a series of major revisions to the various environmental statutes since the 1990s.⁷

As both environmental regulations and their enforcement have been enhanced since the mid-1990s, it would be interesting to examine the innovative activities in Taiwan. This would give a general understanding about the development of environment-friendly technologies and the possible relationship between policy stringency and environmental innovations in Taiwan. As there is no data on environmental R&D in Taiwan, this study shows the trend of the issued patents on five categories of environmental innovations. The categories of environment-friendly technologies, referred to in Hascic *et al.* (2008), are air pollution, water pollution, waste disposal, noise protection, and environmental monitoring technologies.⁸

Figure 1 displays the trends of environmental innovations during the 1980–2009 period. Overall, the trends of the five technologies are similar, showing a slow annual increase in the 1980s and then a boom since the early 1990s. In the 1980s, the Taiwanese government generally continued to focus on economic growth, and therefore the development of environmental policies under their growth-driven economic strategy was constrained (Yeh, 1999). One possible reason is the inefficient implementation of environmental protection

⁶ RCA is an American electrical appliances company, which established its Taiwan affiliate in 1970. During its operating period, the company persistently released toxic chemicals into the environment. In 1988, when the RCA plant was sold to Thomson Inc. of France, the buyer drilled wells to investigate the quality of water and soil and found high level of toxic chemicals. This plant was forced to shut down in 1992, and then the event was divulged to the public.

⁷ For the legislation and revising progress of individual environmental statutes, please see the official website of the Environmental Protection Administration (EPA) of Taiwan. See <http://law.epa.gov.tw/en/>.

⁸ For the corresponding IPC classifications for each environmental technology, see the appendix in Hascic *et al.* (2008). One point worth noting is that the English version of the Taiwan patent search system is not well designed as that in the U.S., and the searching results are not very precise. Moreover, we do not count the design patents, as its classification system differs with IPC classification.

by the Taiwanese government at its early regulatory stage (Lyons, 2009). As already mentioned, the RCA event in the early 1990s stimulated an increasing awareness of environmental protection among the people to pursue a higher living quality, inducing explosive technological development. More specifically, a series of stringent policies have been implemented since the early 1990s.

[Insert figure 1 approximately here]

Overall, waste disposal and noise control technologies are placed first and second respectively, in terms of patent numbers, whereas the number of issued patents of environmental monitoring technology remained the least during the 1980–2009 period. Turning to individual technologies, the patents of waste disposal technology increased sharply, starting in the early 1990s. This might be due to the promulgation of an influential stringency policy, the Waste Disposal Act, which added more articles regarding the general waste clearance and disposal fee collection regulations in 1991, inducing firms to engage in waste disposal patenting. Another rapid increase occurred in 2000–2001, which possibly was due to another major revision that added new articles—from 36 to 70 articles—in 2001. Besides, further revisions were added in 2004 for stricter penalty payments, and this might explain the dramatic upsurge in corresponding patenting activities in 2004.

Noise-reducing patents rank second, although the Noise Control Act was promulgated as late as in 1983. Interestingly, after some fluctuations in the 1990s, noise-reducing patents experienced a continuously sharp growth during the 2002–2005 period, which might be owing to an augmented Noise Control Act and strengthening of the Enforcement Rules in 2003. In fact, urbanization has resulted in the demand for noise-lowering technology, and noise technology can be widely adopted in various electronics appliances. The market-oriented mechanism is probably the main reason of the increased innovations in noise technology.

While economic growth remained relatively stable before 1998, patents relating to air pollution, water pollution, and environmental monitoring technologies showed a rapidly increasing trend, although there were severe fluctuations in the previous decade. These increasing trends were caused by market demand on the one hand; on the other hand, the stringent environmental regulations may have been a driving force. For example, The Air Pollution Control Act was modified in 1999, authorizing the Environmental Protection Act to designate the Total Quantity Control Zones; these were then further revised in 2002 and 2006.⁹ Similarly, the Water Pollution Control Act was modified substantially in 2000, 2002, and 2007.¹⁰ Additionally, some new statutes regarding water regulations were enacted, such as the Marine Pollution Control Act in 2001. Compared with other environmental technologies, the number of patents issued for environmental monitoring exhibits a pretty low level in Taiwan.

From the above preliminary statistical analysis, there seems to be a positive relationship between the stringency of environmental regulations and innovations in Taiwan, as the number of patents has generally increased quickly after the implementation of the revised environmental regulation.

4. Empirical Model and Data Sources

4.1 Effects of environmental regulations on R&D activities

To examine the effect of environmental regulations on R&D and its indirect effect on productivity caused by induced R&D in Taiwan, this study adopts the two-step approach developed by Hamatomo (2006). In the first step, we focus on whether and how the stringency of environmental regulations influences R&D expenditure in Taiwan's manufacturing industries; we specify the empirical model as follows:

⁹ The Total Quantity Control Zones were designated according to topographical and meteorological conditions so that the release of air pollutants can be better controlled for.

¹⁰ In the 2000 revision, 13 out of 63 articles were revised. The 2002 revision extended the number of articles from 63 to 75.

$$\begin{aligned} \ln RD_{it} = & \beta_0 + \beta_1 \ln PAF_{i,t-1} + \beta_2 \ln PACE_{i,t-1} + \beta_3 CR4_{i,t-1} + \beta_4 FOR_{i,t-1} \\ & + \beta_5 GROWTH_{i,t-1} + \beta_6 \ln SIZE_{i,t-1} + \beta_7 \ln SIZE_{i,t-1}^2 + \beta_8 \ln CAP_{i,t-1} \\ & + \beta_9 PROFIT_{i,t-1} + \beta_{10} \ln TI_{i,t-1} + \beta_{11} EXPR_{i,t-1} + u_i + \varepsilon_{it} \end{aligned}$$

(1)

where RD is an industry's R&D expenditures.¹¹ The subscripts i and t denote industry and year, respectively.

As for the explanatory variables, this study includes mainly PACE and industry-specific characteristics. One of the main purposes of this study is to evaluate the stringency of environmental regulations on influencing R&D, suggesting the importance of adequate measures of environmental regulations. The common approach in the existing literature is to use PACE. Unlike previous studies adopting either abatement capital cost (Jaffe and Palmer, 1997; Hamamoto, 2006) or abatement operating cost (Brunnermeier and Cohen, 2003; Gray and Shadbegian, 2003), this study includes both pollution abatement fees (PAF) and PACE. PAF include the costs and expenditures related to abatement operation, maintenance, supervision, tests and inspection, and pollutant emission fees. PACE gives the sum of control equipment expenditure on wastewater, waste gas, waste disposal, and noise. More specifically, detailed information on PACE would enable us to divide PACE into the four types of abatement capital expenditure on various pollutants. Most studies have confirmed a positive relationship between stringent policies and R&D, and so a significant positive coefficient associated with the expenditure variables can be expected.

Based on the structure-conduct-performance (SCP) paradigm, we include various industry-specific control variables. $CR4$ denotes the four-firm concentration ratio in an industry. The Schumpeterian hypothesis predicts that highly concentrated markets enhance the appropriability of returns to R&D, suggesting that market concentration is a crucial determinant of R&D intensity. Many empirical studies have examined the market

¹¹ This study adopts the overall R&D expenditure as proxy for innovation, because information about industry-level environmental patents and environmentally specific R&D expenditure are not acquirable. Hamamoto (2006) also adopts the overall R&D investment as the proxy of innovations.

concentration–R&D nexus and found a positive relation.¹² *FOR* denotes the share of foreign ownership in an industry; it captures the potential difference in R&D activity due to ownership structure. Industrial growth (*GROWTH*) is measured by the growth rate of industry sales. A growing market provides incentives for firms to pre-empt innovation in order to acquire a larger market share, thereby inducing more R&D. Industry size (*SIZE*), which is measured by the number of employees in an industry, is the long-standing concern factor on influencing R&D expenditure variation. Generally, a larger industry tends to undertake more R&D. Aghion *et al.* (2005) suggest an inverse U relationship between size and innovation. We thus include the square term of size to test the possible non-linearity relation. Capital intensity (*CAP*) is measured by the fixed capital per employee. It serves as an alternative determinant that might positively correlate with R&D, because capital-intensive industries generally need to exploit this production feature in coordination with development of new technologies or processes.

Profitability (*PROFIT*) is a performance variable. The financing source of R&D is an age-old issue for economists who share the view that internal finance is the most important source available for firms to undertake R&D. The findings in most previous studies seem to be in accord with this argument,¹³ suggesting that profitability can provide the flow of internal finance to acquire technology through R&D. The term *TI* denotes expenditure on technology imports. For a non-technology-frontier country, technological capability can be developed through in-house R&D, and/or can be acquired externally. How technology imports influence R&D activity depends on whether their relations complement or substitute each other. Finally, with regard to export intensity (*EXPR*), the exports to sales ratio captures an industry's international linkage. The international market is generally more competitive than the domestic market. Firms deciding to enter the international market generally possess higher productivity through

¹² See Aghion *et al.* (2005) for a comprehensive literature review regarding the Schumpeterian hypothesis.

¹³ See Hall (2002) for a comprehensive survey on the financing of R&D.

R&D, implying that an industry with higher export intensity has higher innovation propensities.¹⁴ The terms u_i and ε_{it} represent the unobserved industry-specific heterogeneity and white noise, respectively.

Jaffe and Palmer (1997) and Hamamoto (2006) claim the existence of a time lag between stringent environmental regulations and R&D. Following their specification, expenditure on pollution control enters the equation in the form of a 1-year lagged expenditure. Moreover, to avoid the endogenous problem in the S-C-P paradigm, all other control variables are also specified in 1-year lagged forms.

4.2 Impacts of environmentally induced R&D on TFP

Based on the estimated incremental R&D expenditures, if any, significantly induced by pollution abatement relevant costs and expenditures in the first stage, the study further examines the impact of induced R&D on productivity. The empirical model is specified as below:

$$\ln TFP_{it} = \beta_0 + \beta_1 \ln RD1_{it} + \beta_2 \ln RD2_{it} + \beta_3 (\ln RD1_{it} \times DH_i) + \beta_4 \ln TI_{it} + \beta_5 CR4_{it} + \lambda TIMED + \delta_i + \varepsilon_{it} \quad (2)$$

where TFP denotes the total factor productivity of industry i in year t .

As widely discussed in the literature, stringent environmental regulations can encourage capital turnover in firms and lead to improved productivity. However, Hamamoto (2006) does not support this effect when he estimates the productivity effect of induced R&D, as in equation (2). To soften this problem and obtain a reliable estimate for this indirect productivity effect, this study adopts the TFP measure proposed by Levinsohn and Petrin (2003). Their semi-parametric approach can deal well with problems of endogeneity and unobservable heterogeneity in determining inputs, leading to a more adequate TFP measure (Wooldridge, 2009).

$RD1$ denotes the environmentally induced R&D obtained from estimating equation (1),

¹⁴ During the study period of 1997–2003, the trend of R&D expenditure is relatively smooth, so time effects are not discussed in this specification.

and $RD2$ is the remaining R&D expenditure, which is measured by total R&D expenditure minus the induced R&D ($RD1$).¹⁵ DH is a dummy variable that equals unity if an industry is energy-intensive and/or pollution-intensive.¹⁶ The interaction terms of $\ln RD1$ and DH capture the potential difference in productivity-enhancing effect brought about by induced R&D between energy-/pollution-intensive industries and other industries. Moreover, we also take TI and $CR4$ into account in the productivity equation. $TIMED$ is a series of time dummies, capturing the time effect on influencing productivity. Again, unobserved industry-specific heterogeneity (δ_i) is also controlled for.

4.3 Data sources

To examine the influences of environmental regulations on R&D and the consequent indirect effect on productivity in Taiwan, this study uses the manufacturing plant surveys (hereafter MPS) conducted by Taiwan's Ministry of Economic Affairs. These surveys are conducted annually, except in years when the quinquennial *Industrial and Commercial Census* is conducted, as in 2001. Thus, the dataset we utilized covers the 1997–2000 and 2002–2003 periods. The use of MPS is motivated by the desire to analyze the recent trends of stringent environmental regulations and utilize the advantages of an annual panel. The period is also chosen to avoid substantial concordance problems between version 6 of Taiwan's Standard Industry Classification (SIC) and version 7, which was available for sample plants from 1997.¹⁷ One point worth noting is that the MPS included slightly more than 81,000 plants for the period 1997–2000 and over 73,000 plants for 2002–2003, accounting for about 55% of total firms, on average. MPS are thus sample surveys, but

¹⁵ See Hamamoto (2006) for the calculation of $RD1$.

¹⁶ Taiwan EPA indicates that among all the industrial sectors, iron and steel, petrochemicals, electronics, textiles, pulp and paper, and cement account for approximately three quarters of total industrial CO_2 emissions. These six industries are therefore viewed as energy- and pollution-intensive industries in Taiwan.

¹⁷ It is better if we integrate the census data for 2001 with the MPS data, but this is impossible because of differences in sampling and variable definitions. For example, the census only contains data on the sum of R&D and technology imports, not their separate amounts.

they are representative, and widely used to analyze Taiwan's manufacturing industries. Plant-level data were compiled for 234 four-digit industries for 6 years, for a sample of 1,404 observations.¹⁸ Owing to the use of one-year lagged variables, the number of observations decreased to 1,170.

Table 1 summarizes the definitions and summary statistics of all variables. Except for export intensity and foreign ownership ratios, all other variables at four-digit industry levels were obtained from MPS. Owing to limitation of data, the export intensity and foreign ownership ratio are taken from the Industrial and Commercial Census for the years 1996 and 2001. The export intensity and foreign ownership ratio for 1996 and 2001 are used to explain the data for the years 1997–1998 and 2002–2003, respectively. Data for the years 1999–2000 are interpolated. All nominal variables are deflated into real variables by using manufacturing intermediate input-output price indices for the year 2001.

[Insert table 1 approximately here]

5. Empirical Results

5.1 *Effects of Environmental Regulations on R&D*

Table 2 displays a series of estimates obtained using linear panel data models to estimate equation (1). As all Hausman test statistics are significant at the 1% statistical level, suggesting that the fixed effect model is more appropriate, we give the estimates of the fixed effect model in Table 2.

[Insert Table 2 approximately here]

Models (1) and (2) are the main estimating results based on the relationship between pollution control expenditures and R&D expenditures in Taiwan. With and without controlling for the time effect, the estimates are almost the same in both models. Does the stringency of environmental regulations stimulate industrial R&D expenditure, and if so,

¹⁸ At the 4-digit level, there are actually 248 manufacturing industries, but 14 industries were very small, reporting zero sales for one or more years, and were therefore excluded from the sample.

to what extent? We first addressed the variables of concern in this study, $\ln PAF$ and $\ln PACE$. The estimated coefficient for the pollution control fee (PAF) variables is positive and statistically significant at the 1% statistical level, after controlling for other potential influences. This result is consistent with earlier findings by Brunnermeier and Cohen (2003) and Gray and Shadbegian (2003), that stronger environmental regulations do stimulate firms to increase their R&D investment. Moreover, the estimated coefficients of PAF in models (1) and (2) suggest that R&D expenditures would be triggered by about 0.1% in case of a 1% increase in pollution abatement fees. Interestingly, the estimated coefficient of $PACE$ is not statistically significant in models (1) and (2), implying that there is no significant evidence that more pollution abatement capital expenditures can induce R&D expenditure. This contradicts the U.S. (Jaffe and Palmer, 1997) and Japanese (Hamamoto, 2006) findings that more $PACE$ brings about significant R&D enhancement effects.

Why do pollution control fees rather than capital costs have a positive influence on R&D expenditure in Taiwan? The intuitive explanation is that Taiwan's manufacturing industries might take different attitudes toward the increasing burdens of operating fees and capital investments in response to more stringent environmental regulations set up by the government. In fact, this result can be reasonably attributed to a legal factor. According to Article 6 of the Statute for Upgrading Industries (SUI), the most important industrial policy instrument, tax incentives, are provided for adopting pollution control equipments. Under the Article 6 regulations of the SUI, 7% of the investment in pollution control equipment may be credited against the amount of the profit-seeking enterprises' income tax payable for the current year. Moreover, equipments that have been proved useful and specialized in air pollution control, water pollution control, noise pollution control, waste disposal, vibration control, and environmental surveillance could be exempt from import duties and business tax.

As the expenditure on pollution control equipment would generally be a one-time matter for a long period, this tax benefit can lead to a situation in which firms desire to simply buy equipment rather than engage in costly pollution control technology innovation. As a result, the burden of capital cost brought about by stricter environmental regulations is not a conclusive factor to alter R&D behavior. Alternatively, the burden of pollution abatement is a persistent and variable expenditure, and firms may be fairly conscious of heavier operating cost burdens over time due to more stringent environmental policies. Unlike capital investment used for pollution control, there are no credit benefits to relieve the spending on matters such as abatement operation, maintenance, supervision, test and inspection, and pollutant emission fees. Faced with higher abatement fee expenditures, firms would be driven to undertake additional R&D in response to environmental requirements.

Although PACE overall has no significant influence on spurring R&D expenditure, this study further examined the possible R&D inducement effects that could be stimulated by individual PACE on water, gas, waste, and noise pollution controls. The estimated results are shown in Table 2, models (3) to (6). One interesting finding is that among the four estimated coefficients for various pollution control expenditure, the coefficient of capital expenditures on wastes disposal ($\ln WASTE$) is positive and significant at the 10% statistical level, implying that stringent environmental regulations in waste disposal seems to effectively induce more R&D activity. This finding echoes the development depicted in Figure 1, in which the number of patents issued on waste disposal technology increases sharply since the 1990s and accounts for the highest proportion among the five environmental technologies in Taiwan.

From the above analyses, more stringent environmental regulations in terms of pollution control expenditures overall exhibit a significant positive influence on inducing more R&D, especially on pollution abatement fees. Our findings support the arguments in

existing studies regarding the positive relationship between stringent policies and R&D. PACE tends to have a smaller stimulation effect on R&D because of the preferential tax credit on purchasing pollution control instruments. It casts doubts on the adequateness of policy incentives on pollution capital expenditure, as it not only causes erosion of tax but also lowers the efforts to undertake more R&D activity in firms.

As for the influences of other control variables, the results obtained overall are consistent with theoretical estimations. An industry with a higher concentration ratio, a higher sales growth rate, and a larger scale tends to spend more on R&D, *certis paribus*. In addition, the coefficient for *TI* is positive and significant in all estimates, showing that a 1% increase in expenditure on technology imports induces a 0.032% rise in R&D, on average. It suggests a complementary relationship between technology imports and in-house R&D by absorbing knowledge embodied in imported technologies, and then undertaking adaptive R&D. There are no significant effects of foreign ownership structure and exports on R&D, which may be owing to the imprecise measures on these two variables.

5.2 Impact of Environmentally Induced R&D on productivity

In this subsection, we mainly focus on the impacts of environmentally induced R&D on TFP, testing whether the Porter hypothesis is supported in the case of Taiwan. Since pollution abatement fees are found to bring about significant R&D enhancement effects, as shown in Table 2, we first calculate the amount of R&D (*RD1*) induced by stricter environmental regulations. Following Hamamoto (2006), environmentally induced R&D (*RD1*) and non-environmentally induced R&D (*RD2*) are calculated as follows:

$$RD1_{it} = \hat{\beta}_{PAF} \times [\Delta PAF_{it,t-1} / PAF_{it-1}] \times RD_{it} \text{ and } RD2_{it} = RD_{it} - RD1_{it} \quad (3)$$

Before examining the productivity effect of induced R&D, we look at the incremental results and try to find out “to what extent is industrial R&D investment induced by stringency of environmental regulations.” We therefore first calculate the induced R&D

based on equation (3) and then its share to total R&D, so as to provide an insightful implication.¹⁹

Table 3 displays the ratios of environmentally induced R&D to total R&D over the period 1998–2003. We clearly note that the corresponding shares to R&D spending range between 1.141% and 6.135%, with an average of 4.267%. It is hard to conclude whether this R&D inducement effect is considerable, as there is no similar study in the existing literature for comparison. However, Huang and Yang (2011) indicate an R&D expenditure of 5.30% to 13.91% being induced by R&D tax credit during the 2001–2005 period, suggesting that the environmentally induced R&D effect shown above is not very significant.

[Insert Table 3 approximately here.]

Returning back to the test of the Porter hypothesis, Table 4 shows a series of estimates of the influence of induced R&D on industrial productivity. We can only show the results obtained using the fixed effect of panel data model, as all the Hausman tests reject the null hypothesis at the 1% statistical level.

[Insert Table 4 approximately here.]

Controlling for the time- and industry-specific effects, the coefficients of $\ln RD1$ is positive and significant at the 1% statistical level in models (1) to (3), implying that environmentally induced R&D does indeed contribute to productivity in Taiwan's manufacturing industries. This finding is consistent with the Japanese case shown in Hamamoto (2006) that supports the Porter hypothesis of a possible win-win situation. That is, a stringent environmental regulation can indirectly promote firms' competitiveness in terms of productivity through induced R&D activity. The coefficient of $RD2$, of course, is found to be positively related to productivity in all estimates, because R&D is the primary source of productivity. Specifically, the coefficient of the estimated

¹⁹ When the calculated $RD1$ turns out to be negative, it is treated as zero because it makes no sense that easing pollution abatement pressures would play a driving force in reducing R&D investment by firms. The procedure also ensures that the calculated $RD2$ will not exceed the actual values of total R&D expenditures.

magnitude of RD1 is substantially lower than that of RD2, suggesting that environmentally induced R&D does not effectively contribute to productivity compared to the scheduled R&D.

Furthermore, the coefficient for the interaction term between induced R&D and an energy-/pollution-intensive industry dummy is not statistically significant. This indicates that there is no significant evidence that energy-/pollution-intensive industries benefit more through productivity brought about by environmentally induced R&D expenditures, even though they are generally burdened with greater abatement fees.

Technology import is found to be positively related to productivity in Taiwan's industries, which is consistent with previous finding in Chen and Yang (2006), supporting the view that technology imports serve as a crucial external source of technological capability. The coefficient for CR4 is insignificant, implying that a higher degree of industry concentration does not necessarily contribute to an increase or decrease in productivity. Finally, the magnitude of the estimated coefficients on year dummies reveals an increasing trend, suggesting that Taiwan's industries experienced an increasing productivity during the study period of 1997–2003.

5.3 The direct effect of environmental regulations on productivity

As mentioned in the literature review, there is a line of research directly relating environmental regulations to productivity to test the Porter hypothesis. Moreover, our first-stage analysis has shown that PACE on capital seems to have no significant impact on R&D. This subsection further examines the direct effect of stringent regulations on industrial productivity, so as to provide insightful results. Referring to Gray and Shadbegian's (2003) specification and equation (2), the empirical model is as follows:

$$\begin{aligned} \ln TFP_{it} = & \beta_0 + \beta_1 \ln RD_{it} + \beta_2 \ln PAF_{i,t-1} + \beta_3 \ln PACE_{i,t-1} \\ & + \beta_4 \ln TI_{it} + \beta_5 CR4_{it} + \lambda TIMED + \delta_i + \varepsilon_{it} \end{aligned}$$

(4)

Previous studies maintain that stringent environmental regulations may cause firms to change their behavior on combinations of inputs. Purchasing abatement capital would raise production costs and result in a negative impact on productivity in the short run, although the increase in capital turnover may lead to improved productivity in the long run. This endogenous issue should be taken into account when calculating TFP. To obtain robust estimates on the relationship between environmental regulations and productivity, this study adopts two measures on TFP. One is the previously adopted measure developed by Levinsohn and Petrin (2003), and the other is the conventional value-added measure.

Table 5 displays the estimate results obtained using various productivity measures as the dependent variables. Despite all estimates being quite similar, it provides important implications for the Porter hypothesis. The estimated coefficients for both one-year lagged pollution control fees ($\ln PFA$) and capital ($\ln PACE$) are positive and significant at the conventional statistical level in all estimates. This result supports the Porter hypothesis that a stringent environmental regulation, in terms of either burden of pollution control capital or pollution abatement fees, is positively related to industrial productivity. It suggests the possibility of the win-win situation in which both a better environmental quality and firm competitiveness can coexist. This finding is consistent with the results of more recent studies in this line of research, for example, Berman and Bui (2001) for the U.S. and Hamamoto (2006) for Japan.

[Insert Table 5 approximately here.]

Crucially, the estimated productivity elasticity of PACE on capital is much smaller than that of pollution control fees in all estimates, implying that productivity can be more efficiently improved by stimulating pollution control fees rather than PACE on capital. As mentioned previously, the SUI contains articles providing tax credit for purchasing pollution control machinery, and this is probably the main reason why the low productivity enhancing effect induced by pollution control capital expenditure is lower

than that stimulated by pollution abatement fees.

6. Concluding Remarks and Policy Implications

This study investigates whether stricter environmental regulations would induce more R&D expenditures and, if so, the further impact of induced R&D on industrial productivity in Taiwan. On the basis of a panel dataset of 234 manufacturing industries during the period 1997–2003, we adopt a two-stage framework to implement the estimation, and we derive interesting and important findings. Various estimates confirm a significantly positive relationship between pollution abatement fees and R&D expenditures, but there is no evidence to support an R&D-inducement effect brought about by PACE. The insignificant effect of PACE on R&D contradicts the findings of Jaffe and Palmer (1997) and Hamamoto (2006). This result is mainly attributed to the tax credit instruments favoring the purchase of pollution control capital equipment in Taiwan. Importantly, as PACE is further classified into the various capital costs of water, gas, waste, and noise control, we find a significant R&D inducement effect brought about by capital cost of waste control. This finding is consistent with the aggregate patent information result that waste disposal technology has led to the most number of patents among the five environmental technologies. A further examination of the indirect effects of stricter environmental regulations on productivity shows that environmentally induced R&D significantly contributes to industrial productivity. However, the productivity effect of induced R&D is less efficient compared with that of regular R&D. Moreover, the alternative estimation that directly examines the influence of pollution control expenditures on industrial productivity shows that both capital cost of pollution control and pollution abatement fees have a significantly positive impact on promoting productivity. Results drawn from various estimating strategies suggest the possibility of a win-win situation in which both stringent environmental regulations and firm

competitiveness can coexist, providing evidence for the so-called Porter hypothesis.

From the above analyses, this study derives two policy implications. First, a win-win situation can be reached only if there are well-designed environmental regulations. Taiwan has a wide range of tax incentives for investments in pollution control equipments, so firms are apt to buy capital equipment rather than undertake more R&D. This is probably the main reason why we find PACE to have an insignificant effect on R&D. Thus, the Taiwanese government should reconsider its policy of tax credit for purchasing pollution control capital equipment. The alternative strategy would be to directly provide more appealing incentives to undertake environmentally friendly R&D activities. Second, this study estimates the individual effects of pollution abatement fees and capital expenditures on overall R&D expenditures rather than on environmental R&D expenditure, owing to the limitation of data source. To the best our knowledge, Taiwan has no nationwide statistics on environmental R&D. Besides, it is very difficult to compile industry-level environmental patent data because of differences in industry and patent classifications. Therefore, the government of Taiwan should devote more of its efforts to conduct general and up-to-date surveys of environmental R&D activities. It is also necessary to define environmentally friendly technologies more accurately in Taiwan.

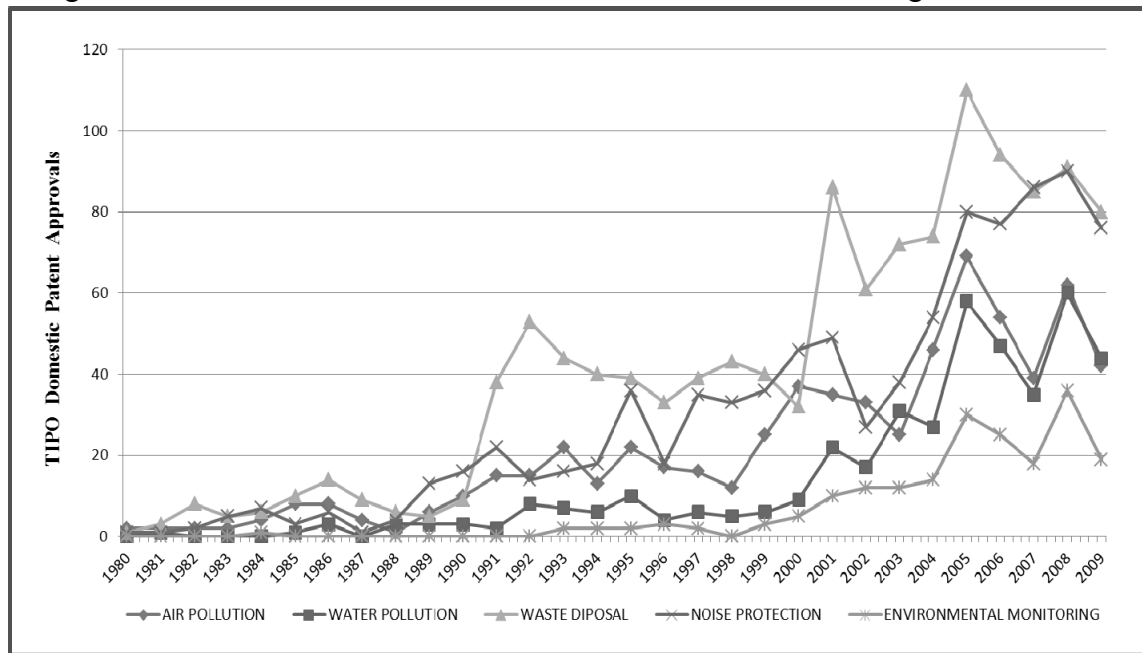
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Figure 1 Number of Domestic Patents in Five Environmental Technologies in Taiwan



Source: Intellectual Property Office of Taiwan

Table 1 Definitions and summary statistics of all variables

Variable	Definitions	Mean	S.D.
<i>RD</i>	industry-funded R&D expenditures (thousand NT dollars)	540277.9	2325684
<i>PAF</i>	Pollution abatement fees: costs and expenditures related to abatement operation, maintenance, supervision, test and inspection (including personnel expenses), and also pollutant emission fees, etc. (thousand NT dollars)	62215.09	196914.5
<i>PACE</i>	Total pollution abatement capital expenditures: the sum of waste water, waste gas, wastes disposal, and noise pollution abatement capital expenditures. (thousand NT dollars)	54943.04	248579
<i>Water</i>	Waste water pollution abatement capital expenditures (thousand NT dollars)	23469.24	104710.9
<i>Gas</i>	Waste gas pollution abatement capital expenditures (thousand NT dollars)	22424.84	147410.4
<i>Wastes</i>	Wastes disposal pollution abatement capital expenditures (thousand NT dollars)	7052.679	31580.03
<i>Noises</i>	Noise pollution abatement capital expenditures (thousand NT dollars)	1871.542	9045.661
<i>CR4</i>	Four-plant concentration ratio	0.43306	0.23981
<i>FORI</i>	Foreign ownership ratio (%)	3.81551	5.09428
<i>MS</i>	Growth rate of industry sales (%)	23.32951	128.0234
<i>EMP</i>	Number of labor employed in each manufacturing industry	9456.615	13957.5
<i>CAP</i>	Capital intensity: Ratio of capital to labor employed (thousand NT dollars/person)	220.7783	380.5595
<i>TI</i>	Technology import expenditures (thousand NT dollars)	183212.5	1185539
<i>EXPI</i>	Export intensity: ratio of exports to total sales of industry (%)	24.16977	20.65566
<i>PROFIT</i>	Operating profit ratio: (Sales - Operating expenditures)/Sales (%)	6.76419	9.81869
<i>TFP</i>	Total factor productivity: using methods developed by Levinsohn and Petrin (2003)	9.327	0.740
<i>VA</i>	Value added: sale minus intermediate goods (NT\$ million)	13191.995	28429.910
<i>DH</i>	Dummy variable: energy- and pollution- intensive manufacturing industries defined by Taiwan EPA (Iron and steel, petrochemicals, electronics, textiles, pulp and paper, and cement)	0.28205	0.45016

Note: The summary statistics reported are reported by the pooling data of 234 Taiwan's manufacturing industries for the period of 1997-2003 (excluding 2001). All of the monetary measures above are deflated to the 2001 NT\$ using manufacturing intermediate input-output price indices.

Table 2. Effects of environmental regulations on R&D expenditures

Variable	Model 1 (FE)	Model 2 (FE)	Model 3 (FE)	Model 4 (FE)	Model 5 (FE)	Model 6 (FE)
<i>lnPAF</i>	0.098*** (0.000)	0.101*** (0.000)	0.098*** (0.000)	0.097*** (0.000)	0.094*** (0.000)	0.097*** (0.000)
<i>lnPACE</i>	-0.003 (0.874)	-0.010 (0.663)				
<i>lnWater</i>			-0.011 (0.548)			
<i>lnGas</i>				0.006 (0.744)		
<i>lnWaste</i>					0.031* (0.097)	
<i>lnNoise</i>						0.018 (0.292)
<i>CR4</i>	0.910* (0.087)	0.887* (0.096)	0.922* (0.082)	0.895* (0.091)	0.852 (0.107)	0.900* (0.089)
<i>FOR</i>	-0.030 (0.119)	-0.029 (0.128)	-0.030 (0.116)	-0.030 (0.120)	-0.028 (0.134)	-0.029 (0.127)
<i>MARKET</i>	0.003*** (0.000)	0.003*** (0.000)	0.003*** (0.000)	0.003*** (0.000)	0.003*** (0.000)	0.003*** (0.000)
<i>lnEMP</i>	2.783*** (0.000)	2.758*** (0.000)	2.771*** (0.000)	2.799*** (0.000)	2.881*** (0.000)	2.830*** (0.000)
$[\lnEMP]^2$	-0.113*** (0.000)	-0.113*** (0.000)	-0.112*** (0.000)	-0.115*** (0.000)	-0.123*** (0.000)	-0.118*** (0.000)
<i>lnCAP</i>	0.096 (0.223)	0.097 (0.224)	0.096 (0.219)	0.087 (0.264)	0.077 (0.324)	0.088 (0.259)
<i>lnTI</i>	0.032* (0.061)	0.036** (0.039)	0.032* (0.058)	0.031* (0.065)	0.031* (0.067)	0.031* (0.068)
<i>EXPR</i>	-0.002 (0.776)	-0.001 (0.839)	-0.002 (0.781)	-0.002 (0.771)	-0.001 (0.805)	-0.002 (0.784)
<i>PROFIT</i>	-0.0090 (0.182)	-0.009 (0.198)	-0.009 (0.170)	-0.009 (0.188)	-0.009 (0.191)	-0.009 (0.188)
Time dummy	No	Yes	No	No	No	No
R-square	0.577	0.580	0.5776	0.5761	0.5729	0.5739
Hausman test	173.34** *	168.46** *	177.44** *	172.62** *	178.95** *	179.90** *
<i>F</i> -test all $\alpha_i = 0$	5.22***	5.19***	5.21***	5.22***	5.25***	5.22***
Observations	1170	1170	1170	1170	1170	1170

Note: Figures in parentheses are *p*-values. ***, **, and * indicate significance at 1%, 5%, and 10% levels respectively.

Table 3. Annual ratio of *RD1* to total R&D

year	<i>RD1</i> / RD (%)
1998	4.205
1999	5.886
2000	6.135
2002	1.141
2003	3.967

Table 4 Impacts of environmentally induced R&D on total factor productivity

Variable	Model 1 (FE)	Model 2 (FE)	Model 3 (FE)	Model 4 (FE)
<i>lnRD1</i>	0.007*** (0.004)	0.009*** (0.002)	0.007*** (0.009)	
<i>lnRD2</i>	0.021*** (0.000)	0.022*** (0.000)	0.018*** (0.000)	
<i>lnRD</i>				0.065*** (0.000)
<i>lnRD1*DH</i>		-0.006 (0.169)	-0.006 (0.152)	
<i>lnTI</i>			0.027*** (0.000)	0.022*** (0.000)
<i>CR4</i>			-0.011 (0.920)	0.008 (0.939)
<i>t99</i>	0.060** (0.027)	0.061** (0.025)	0.058** (0.027)	0.058** (0.023)
<i>t00</i>	0.135*** (0.000)	0.133*** (0.000)	0.123*** (0.000)	0.102*** (0.000)
<i>t02</i>	0.179*** (0.000)	0.179*** (0.000)	0.149*** (0.000)	0.141*** (0.000)
<i>t03</i>	0.215*** (0.000)	0.213*** (0.000)	0.191*** (0.000)	0.205*** (0.000)
R-square	0.286	0.276	0.434	0.544
Hausman test	7863.56***	9549.04***	135.98***	98.85***
<i>F</i> -test all $\delta_i=0$	15.25***	15.27***	13.70***	12.35***
Observations	1170	1170	1170	1170

Note: RD in model (4) denotes overall R&D expenditures. Figures in parentheses are *p*-values. ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.

Table 5 Impacts of PACE on productivity

Dep. Variable	lnTFP (FE)	lnTFP (FE)	lnVA (FE)	lnVA (FE)
lnRD	0.067*** (0.000)	0.061*** (0.000)	0.138*** (0.000)	0.122*** (0.000)
lnPAF_I	0.019*** (0.000)	0.018*** (0.000)	0.037*** (0.000)	0.031*** (0.000)
lnPACE_I	0.010** (0.033)	0.008* (0.055)	0.024*** (0.000)	0.022*** (0.001)
lnTI		0.022*** (0.000)		0.049*** (0.000)
CR4		0.134 (0.215)		-0.559*** (0.000)
YEAR-99	0.064** (0.014)	0.063** (0.012)	0.041 (0.291)	0.034 (0.357)
YEAR-00	0.129*** (0.000)	0.125*** (0.000)	0.156*** (0.000)	0.134*** (0.000)
YEAR-02	0.170*** (0.000)	0.149*** (0.000)	0.071* (0.067)	0.024 (0.528)
YEAR-03	0.251*** (0.000)	0.230*** (0.000)	0.176*** (0.000)	0.120*** (0.001)
R-square	0.211	0.242	0.242	0.315
Hausman test	612.99***	640.37***	654.32***	671.26***
F-test all $\delta_i=0$	10.43***	10.61***	12.64***	12.27***
Observations	1170	1170	1170	1170

Note: Figures in parentheses are p -values. ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.