Tracking environmental innovations and policy regulations in Japan: case studies on dioxin emissions and electric home appliances recycling

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Abstract

Taking dioxin emissions from incineration and the recycling of home electric appliances in Japan as two case studies, this paper aims to clarify the impact of environmental policy on technological innovation. For our case studies, relevant Japanese patent data were gathered and analyzed for the period 1990–2008. To demonstrate that environmental regulations induce technology innovation, we conducted statistical analysis to compare the number of patents related to each regulation between the period under regulation and period outside the regulation. The results show that after the regulations were introduced, new technological developments occurred for most technological types and the total number of related patent applications was larger even when controlling for other exogenous and endogenous factors such as business cycles and expenditures in Research and Development (R&D). We finally argue that while a possible weakness in these types of direct regulations is the lack of incentives for further innovations, they can still induce innovation if they are flexible and with specific targets.

Keywords: environmental policy, induced innovation, lock-in, patent data, recycling

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1. Introduction

Increasing economic growth while minimizing resource consumption and environmental degradation is one of the greatest challenges modern societies face nowadays. The highly inefficient use of natural resources, from their extraction to final disposal, is already damaging the planet (Hawken et al., 1999). While technological innovation has played a central role in providing safer and better lives for many people, it is also apparent that leaving the development of new technologies to the market alone has been one of the causes of technological lock-in, which has prevented the emergence of more sustainable technologies (Morioka et al., 2006). Many studies have challenged the belief that environmental regulations affect the industrial competitiveness of countries. Porter (1991), for example, argued that stricter environmental regulations would trigger innovations and increase the competitiveness of firms. Other studies, in contrast, have found no significant impact of environmental regulations on innovation (Fischer et al., 2003). There have been some studies related to the policy-innovation linkages in Japan. Yarime (2007) for instance, examined the impact of regulations on the chlor-alkali industry in Europe and Japan and found that regulations substantially determine the direction of technological development. Specifically it found that while Europe set for mercury emission standards Japan implemented regulations that focused on phasing out existing mercury processes. Consequently while the European chlor alkali industry still relies on mercury process the Japanese industry has completely phased out that option. Popp (2006) examined innovation and diffusion of air pollution control equipment in the United States, Japan and Germany and found that innovators respond to environmental regulation pressure in their own countries but do not respond to foreign environmental regulations. These studies have been made in the context of comparing trends in Japan and the Western world.

While there many studies that analyze the impact of market-based environmental policy instrument, there are rather few studies that focus on command and control approaches. This study focuses specifically on the latter to analyze the environmental innovation-regulation linkages in Japan. Taking dioxin emissions from incineration and the recycling of home electric appliances in Japan as two case studies this paper tries to clarify not only the influence of environmental regulations on environmental technologies in Japan but also tries to find out how these regulations were driven in the first place. We discuss the relevance of these policies in streamlining technology-push and demand-pull relationships. Specifically, we found that there might be a pattern regarding environmental technological innovations in Japan. Usually these innovations start with social concerns regarding environmental issues or resource scarcity (demand pull). The government then introduces stricter regulations to meet these concerns (policy push), such as emission standards for dioxin, SO_2, or recycling targets for end-of-life products. Finally, the technology development community, such as industrial sectors, develops the innovations necessary to comply with those regulations.

We investigated the Japanese Patent Database to determine whether environmental policies were the actual drivers of specific innovations. To identify the relevant patents, we first analyzed the related technological processes for both dioxin emission reduction and home appliance recycling systems in Japan. We then examined how environmental regulations affect environmental innovation comparing the number of patents related to the regulations between the period under regulation and periods outside the regulation. Furthermore, in order to control for the potential exogenous effects of factors such as business cycles and demand changes, we constructed a model to conduct a regression analysis. The results show that, during the regulation period, the number of related patents for most technological types is larger than in the periods outside the regulation but go back to previous levels once the targets have been met. We argue that while these results suggest a possible weakness in these types of performance-based regulations due to lack of incentives for further innovations, the regulations also induced technological innovation in other processes of the entire life cycles.

2. Japanese environmental regulations and waste management technologies

Waste management policies in Japan since the post-war period have evolved in four main periods: (1) the reactive policies of the post-war period, which focused on public sanitation issues related to rapid industrialization and urbanization, (2) the responsive policies of the mid-1950s through the late 1970s, which introduced classification of waste from general and industrial sources as well as standards for waste disposal, (3) the constructive policies of the 1980s through the mid-1990s that were based on the 3R (reduce, reuse and recycle) principle, and (4) the current integral and proactive policies that focus on decoupling economic development from environmental pressure, promoting sustainable lifestyles based on sustainable production and consumption strategies, increasing quality of life through environmental risk minimization and biodiversity protection, and making efforts to prevent climate change through low-carbon measures (Yabar et al., 2008). From this historical evolution in waste management, we highlight the following two cases to discuss the impacts of environmental policies on technological innovations.

The dioxin problem

The Waste Management and Public Cleansing Law of 1970 promoted end-of-pipe technologies with rapid and high volume treatment capacity, such as incineration. Incineration technology has been important in Japan because of its capacity to reduce waste volume significantly (Japan is a relatively small country with a high population density). Since the daily amount of waste was relatively small in the 1970s, local governments operated mostly small scale and batch-type incinerators. The change in lifestyle of the 1980s due to higher living standards was perhaps the main driver for not only the increase in the amount but also the change in the nature of the waste. This lifestyle change increased demand for products in small packages, which in turn increased the amount of plastic waste generated by both industrial and domestic sources (PWMI, 2004). Public health concerns related to dioxin emission associated with plastic incineration started to increase in the early 1990s. Various studies found that dioxin emissions were higher in low-combustion and batch-type incinerators (see Bagnati et al., 1990; Ohta et al., 1997). To address this public health concern, the government introduced the Law Concerning Special Measures against Dioxin in 1999 (MCDP, 1999). As shown in Figure 1, the law, which set the target at reducing dioxin emissions by 90% by 2003 taking as a base the year 1997, proved to be effective in that the target was surpassed by phasing out small scale incinerators, replacing batch incinerators with continuous-type ones and introducing dioxin trapping technologies (Yabar et al., 2009).

Figure 1 here

Recycling measures for specific wastes

Japanese policies have mainly focused on promoting effective use of resources and minimizing the environmental and health impacts of production and consumption systems (Japan is a resource-dependent country). Since the early 1990s, the government has enacted various laws based on the 3R approach: the Containers and Packaging Recycling Law (1995), the Home Appliance Recycling Law (1998), the Construction Materials Recycling Law (2000), the Food Recycling Law (2000), and the End-of-Life Vehicles Recycling Law (2002) (METI, 2004). These laws targeted specific wastes including: containers and packaging (plastic, glass and paper), electric and electronic home appliances, vehicles, construction materials and food-related wastes. In the case of electric and electronic home appliances, for example, the law targeted four key products: air conditioners, refrigerators, televisions and washing machines. In this case, all the recycling targets were met and surpassed (see Table 1).

Table 1 here

3. The impact of policies on innovation

3.1 Using patents to measure environmental innovations

This section examines the impact of policies on innovation for the dioxin and recycling cases in Japan. Several studies have focused on the impact of environmental policy and regulations on technological innovation. The results of these studies have been mixed. Jung et al. (1996) analyzed the incentive effects of environmental policy instruments to promote advanced pollution abatement technology and found that auctioned permits and emission taxes and subsidies have the greatest impact on innovation. Jaffe et al. (2001) found empirical evidence consistent with theoretical findings that market-based instruments are likely to have greater impacts on environmental technological innovation than command and control approaches. Fischer et al. (2003) analyzed the impacts of auctioned permits, emission taxes and free permits on innovation and found out that each of these can induce innovation but all have similar level of effect. As proxies for measuring innovation trends, such as patent data, have become more available, the number of research initiatives to analyze the effect of policy on innovation has increased. When analyzing technological innovation, the use of patent data provides many advantages (Marinova and McAleer, 2003; Popp, 2005):

- Patent classification provides useful information on the different types of R&D and hence tracks the advances in specific technological fields accurately;
- The dates of applications for patents give information on the level of R&D activity;
- International patent data provide information on the level of diffusion of technologies across international borders;
- Patent citation can be used as an indicator of further knowledge development or knowledge flow; and
- The rate of assigned patents provides information on their commercial or market potential.

The advantages of using patent data are very important when analyzing the effects of environmental policies on technological innovation in this study.

3.2 Empirical analysis

Model specification

In order to determine whether the environmental policies were the actual drivers of specific innovations, we use and analyze the Japanese patent database. For the identification of the relevance of patents, we first identified the related Japanese technological processes for both dioxin emission reduction and home appliance recycling. **Tables 2 and 3** show a summary of the identified patent groups. We used the International Patent Classification Codes and assigned shorter specific codes for the sake of simplicity. **Figure 2** shows the patent citation trends for dioxin related technologies and for home appliance related technologies over the period 1990-2008.

Table 2 here

Table 3 here

Figure 2 here

To see the trend changes, we conduct a t-test analysis to show whether more technological developments occurred under the period of environmental regulations. In the case of dioxin, we divided the periods into: 1990-1996, 1997-2003 and 2004-2008. The rationale for this classification is that the government announced measures to minimize the dioxin emissions from incineration in 1997 (the Dioxin Law was enacted in 1999) and the emission standards were met in 2003. In the case of home appliances, we compared the patent trends before and after 1998 when the Home Appliance Recycling Law was enacted. **Table 4** presents the t-test results. We find that during the regulation period the number of related patents for most technology types is, in general, larger than in the period before regulation or the period after regulation targets had been met.

Table 4 here

In order to control for the potential exogenous effects of factors such as business cycles and demand changes, we also compare the ratios of the case studies related patents to the total number of environment-related patents. (Appendix provides the definition of the environmental-related patents.) The results of the ratios of both dioxin and recycling patents compared to total environmental patents are shown in **Figure 3**. As **Table 5** shows, the ratio of dioxin-related patent to the total was 0.33 under the regulation period and 0.29 under the unregulated period. Likewise, the ratio of recycling-related patent to the total patent was 0.06 under the regulation period and 0.04 in the unregulated period. Again, we conduct the t-test, obtaining the results that the ratios of the environment-related patents are statistically higher under the period, implying that regulations were effective.

Figure 3 here

Table 5 here

Having had these observations, we now demonstrate a regression analysis to examine the policy impact, which technically controls for the potential effects of factors that directly and indirectly affect innovation in a more rigorous way. We follow Popp (2005) in model estimation for innovation: we use a reduced form as the structure of how innovation occurs is too complex to have specification of estimated model. In particular, we hypothesize that the occurrence of innovation in the form of patent application depends on the Research and Development (R&D) behaviour. This is described by the following reduced equation form:

$$\frac{Patent_{t,i}}{PatentTotal_t} = \alpha_0 + \alpha_1 \mathbf{X} + u_t \quad (1)$$

where $Patent_{t,i}$ is a patent application count of technology type i (dioxin or recycling) in year t, *PatentTotal* denotes the total counts of environmental technologies in year t, α are estimated parameters, $\mathbf{X}$ represents R&D expenditures, and u is an error term. The use of the patent ratio as a dependent variable is again to exclude the influence of exogenous trends.

In our model, the effect of the R&D variable is computed by the weighted average of the past R&D expenditure:

$$\mathbf{X} = RD_t + \delta \cdot RD_{t-1} + \delta^2 \cdot RD_{t-1} + \delta^3 \cdot RD_{t-2} + \cdots \quad (2)$$

where δ is a discount parameter (presumably less than one). The R&D effect is defined by a weighted average of the past expenditure in way that older expenditures have less impact. After manipulating the equations (1) and (2), we can then express the equation (1) as (see Brown (1952) for details):

$$\frac{Patent_{t,i}}{PatentTotal_t} = \alpha_0 + \alpha_1 (1-\delta) RD_t + \delta \frac{Patent_{t-1,i}}{PatentTotal_{t-1}} + u_t$$

In this study, we attempt to capture the impact of the environmental policy by year dummy variables, which take a value of one when it is under the regulation period. Positive values of the dummy variable coefficient mean a positive impact of the environmental policy. The regulation periods in each of the cases are defined above. So, our estimation equation is

$$\frac{Patent_{t,i}}{PatentTotal_t} = \alpha_0 + \alpha_1 (1-\delta) RD_t + \delta \frac{Patent_{t-1,i}}{PatentTotal_{t-1}} + PolicyDummy_i + u_t$$

Furthermore, in the model specification, the R&D expenditure variable can be endogenous, possibly affected by other macroeconomic trends. Thus we use GDP as an instrument variable for the R&D expenditure variable. Finally, the R&D expenditure and GDP data are obtained from the Japanese Governmental Cabinet (2011).

Results

Table 6 shows the regression results of the Instrument Variable estimates. As the adjusted R squared values are respectively 0.8 and 0.6 in the dioxin and recycling cases, the overall model fitness is moderate for the two cases. The coefficient of the R&D expenditure is not statistically significant in the dioxin and recycling cases whereas that of the lagged Patent count is significant with a positive sign. Note that these estimated values are less than one: because the coefficients of the lagged patent count represent the discount parameter to capture the past R&D expenditures these results might justify our model specification. Finally, regarding the effect of regulations, the coefficient of the year dummy variable is statistically significant with a positive sign in both the dioxin and recycling cases.

Table 6 here

These results indicate that proper regulations can stimulate the development of environmental technologies. Specifically, in the case of dioxin innovations, health concerns related to dioxin emissions from incineration (demand pull) were probably the main driver behind the government's push to enact stricter regulations. These regulations in turn pushed the industry to allocate more resources to develop the innovations necessary to comply with those regulations. With regard to the home appliance recycling law, the setting of high recycling targets induced the design of innovations to meet those targets. At the same time these regulations may have promoted innovations at the production phase because producers realized that designing easy-to-recycle products would eventually reduce the final disposal costs.

4. Discussion and conclusion

Taking dioxin emissions from incineration and the recycling of home electric appliances in Japan as two case studies, this paper analyzed the impact of policies and regulations on technology innovation. In order to determine whether the environmental policies were the actual drivers of specific innovations, we analyzed the trends in related patents from the Japanese patent database. For the identification of the relevance of patents, we first analyzed the related technological processes for both the dioxin emission reduction and home appliance recycling systems. To analyze how environmental regulations affect environmental R&D, we conducted statistical analyses to compare the number of patents related to the regulations between the period under regulation and period outside the regulation. Generally, during the regulation period, the number of related patents to dioxin emissions and recycling is larger than in the period outside the regulation even after controlling for other factors' effects such as R&D expenditure and business cycles. We also examined the effects of environmental regulations on the development of specific technologies. The results show that the number of related patents for most technological types is larger after the regulations were introduced indicating that proper regulations can stimulate the development of environmental technologies.

Generally, innovation literature has suggested that innovation relies on the postulate that changes in the relative price of the factors of production will spur innovation to economize on the use of the more expensive of those factors (Hicks, 1932). In addition to the price of factors of productions, regulations can also trigger technological innovation (Popp, 2006; Jaffe et al., 2003; Newel et al., 1998). Many studies suggest that market-based instruments are in general more likely to induce innovations than direct regulations (see Popp et al 2009). In line with this, our observations in fact show a decreasing pattern in patent citations once the targets have been met suggesting a possible weakness in these types of regulations. This pattern could be explained by the lack of incentives for further innovations.

However, this view also depends on how to define the boundary of related technologies. We argue that these environmental policies and regulations in Japan may have not only boosted innovations to achieve the specific recycling targets but also promoted innovations based on the product life-cycle. Engineering literature (e.g., Arizawa et al., 2008) shows evidence that recycling policies in Japan induced innovation in eco-design; that is, the relevant industry realized design for easy-to-recycle products that eventually render savings in cost and energy use at the end-of-life phase. Our future research is to demonstrate in-depth analysis on how environmental policy influences innovation in the entire processes in the life-cycles.

Appendix

This appendix presents the definition patent data related to environmental innovation used in our analysis. The selection of the environmental-related patents was based on Acosta et al (2009) and our own criteria (**Table 7**). The environment-related patent, of course, contain the technology types related to dioxin and recycling.

Table 7 here

Acknowledgements

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Figure captions

Figure 1. The impact of environmental policy on dioxin emissions

Figure 2. Patent trends related to dioxin and home appliance innovations

Figure 3: Ratio of case study and total environmental patents

Table captions

Table 1. The impact of environmental policy on home appliance recycling

Table 2. Patents related to dioxin emission reduction technologies

Table 3. Patents related to home appliance recycling technologies

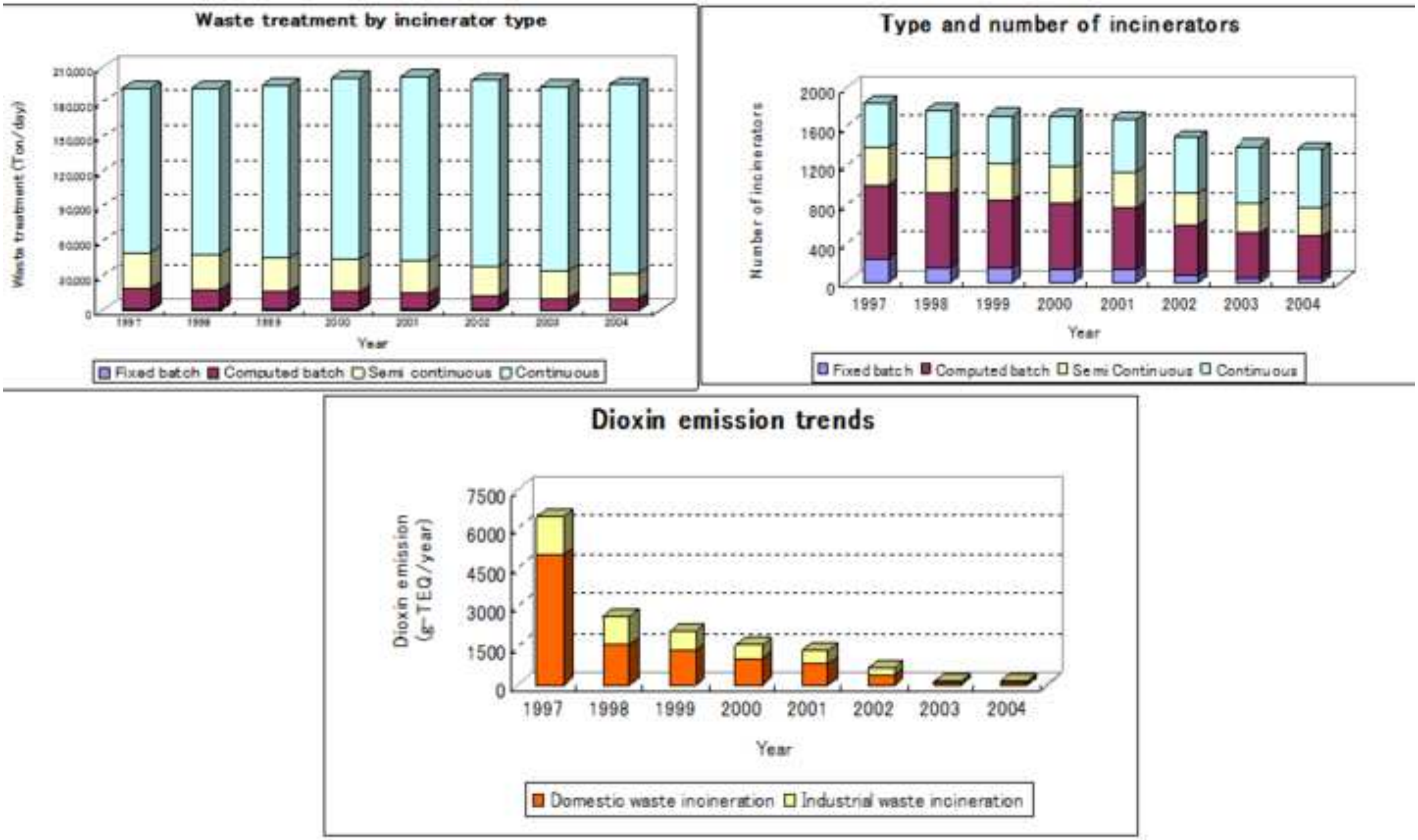
Table 4. Results of t-test comparing the average number of patents inside and outside the regulation period

Table 5: Results of t-test comparing the ratios of the number of patents inside and outside the regulation period

Table 6: Results of regression: instrument variables estimation

Table 7: Patents related to environmental innovations

Figure 1. The impact of environmental policy on dioxin emissions



Figure
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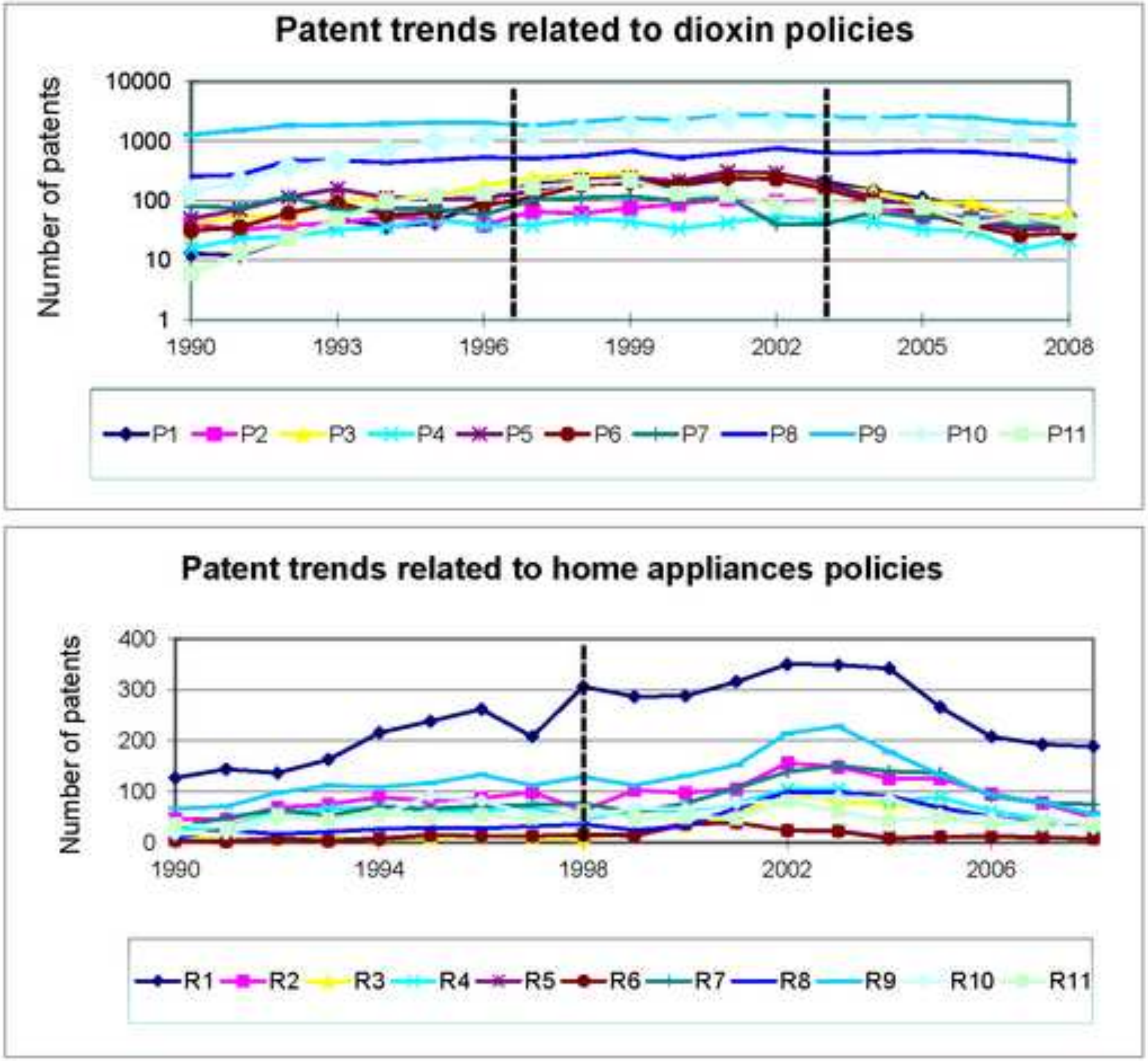
Figure 2. Patent citation trends related to dioxin and home appliance innovations



Figure

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Figure 3: Ratio of case study and total environmental patents

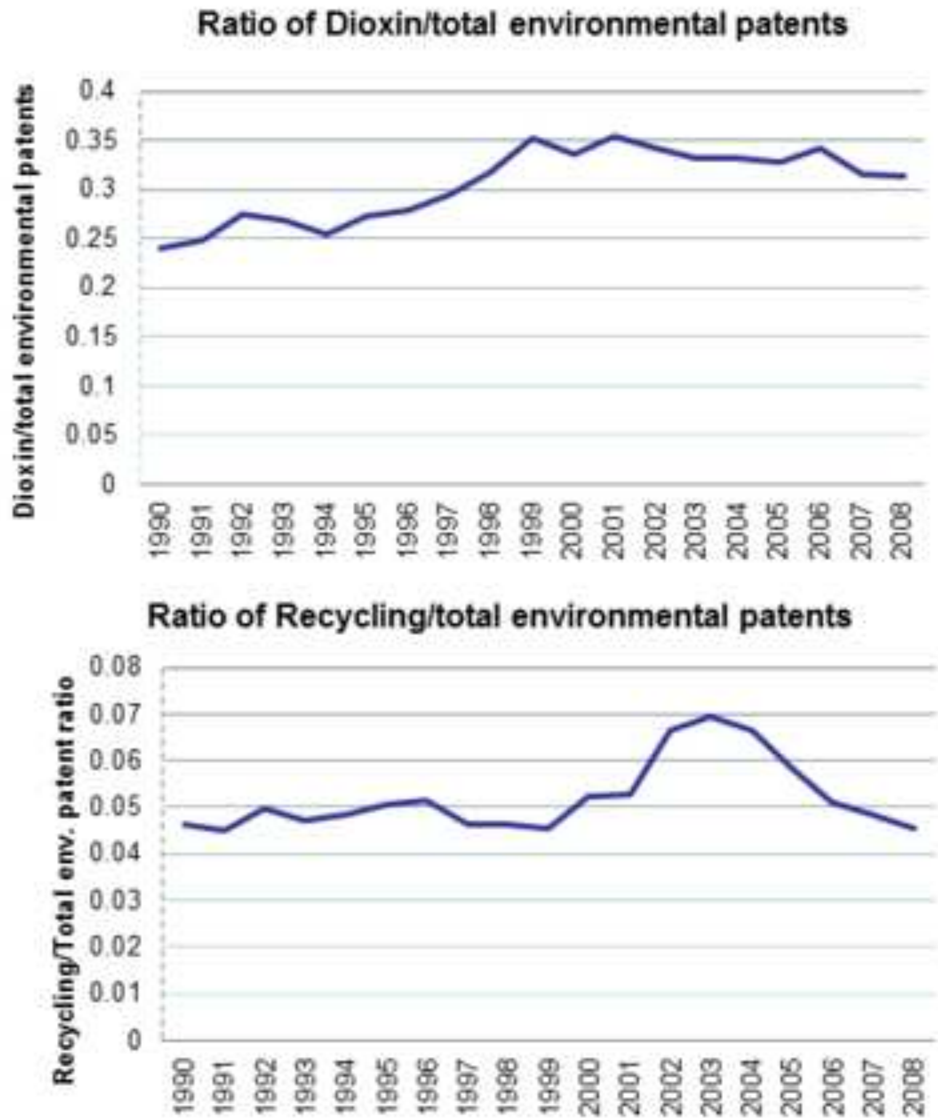

Table 1 The impact of environmental policy on home appliance recycling

Home appliance type	Recycling target	Recycling rate					
		2001	2002	2003	2004	2005	2006
Air conditioner	60%	78%	78%	78%	82%	84%	86%
Television	55%	73%	75%	75%	81%	77%	77%
Refrigerator	50%	59%	61%	61%	64%	66%	71%
Washing machine	50%	56%	60%	60%	68%	75%	79%

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Table 2. Patents related to dioxin emission reduction technologies

Patent Code group (IPC)	Assigned code	Short description of the patent group
F23G5/027	P1	Incineration of waste: pyrolising or gasifying stage
F23G7/06	P2	Incinerators or other apparatus for consuming industrial waste: waste gases and noxious gases, e.g. exhaust gases
F23J1/00	P3	Removal of ash, clinker, or slag from combustion chambers
F23J3/00	P4	Removal of solid residues from passages or chambers beyond the fire, e.g. from flues by soot blowers
F23J15/00	P5	Devices for treating smoke or fumes
F23J15/00*	P6	Devices for treating smoke or fumes (*Without considering SOx and NOx)
F23N5/00	P7	Systems for controlling combustion
B01D46/00	P8	Filters or filtering processes specially modified for the separation of dispersed particles from gases or vapors
B01D53/00	P9	Separation of gases or vapors; recovering vapors of volatile solvents from gases; chemical purification of smoke, fumes, or exhaust gases
B09B3/00	P10	Destroying solid waste or transforming solid waste into something useful or harmless
B09B3/00*	P11	Destroying solid waste or transforming solid waste into something useful or harmless (*Related specifically to plastics and rubber)

IPC: International Patent Classification

Table
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Table 3. Patents related to home appliance recycling technologies

Patent Code group (IPC)	Assigned code	Short description of patent group
B01D21/00	R1	Separation of suspended solid particles from liquids by sedimentation
B03C1/00	R2	Magnetic separation
B03C1/00*	R3	Magnetic separation (*solid-solid separation)
B03C1/02	R4	Magnetic separators
B03C7/00	R5	Separating solids from solids by electrostatic effect
B03C7/02	R6	Separators (solid-solid)
B03B5/00	R7	Washing granular, powdered or lumpy materials; wet separating
B03B5/28	R8	Sink-float separation
B07B1/00	R9	Sieving, screening, sifting, or sorting solid materials using networks, gratings, grids, or the like
B07B4/00	R10	Separating solids from solids by subjecting their mixture to gas currents
B07B7/00	R11	Selective separation of solid materials carried by, or dispersed in, gas currents

Note: IPC: International Patent Classification

Table 4. Results of t-test comparing the average number of patents inside and outside the regulation period

Patent type	t-test hypothesis	Patent type	t-test hypothesis
Dioxin emission reduction	H: μ^{law}-$\mu^{non\text{-}law}$>0	Recycling	H:μ^{law}-$\mu^{non\text{-}law}$>0
Type P1	***	Type R1	**
Type P2	***	Type R2	**
Type P3	***	Type R3	*
Type P4	**	Type R4	***
Type P5	***	Type R5	**
Type P6	***	Type R6	**
Type P7	*	Type R7	**
Type P8	*	Type R8	**
Type P9	**	Type R9	**
Type P10	***	Type R10	Reject
Type P11	***	Type R11	Reject

Note: ***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The regulation period (the presence of the dioxin law) is 1997-2003. The regulation period for the recycling law is 1999-2008.

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Table 5. Results of t-test comparing the ratios of the number of patents inside and outside the regulation period

Patent type	The ratios of the related patents to the total number of environment-related patents		T-test hypothesis and results
	Without law	Under law	$H: \mu^{law}-\mu^{non\text{-}law}>0$
Dioxin emission reduction	0.289 (7)	0.339 (12)	Significant at the 1% level
Home appliance recycling	0.048(9)	0.056 (10)	Significant at the 5% level

Note: The number of observations (years) is in parenthesis.

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Table 6. Results of regression: instrument variables estimation

	Dioxin case		Recycling case	
	Coefficient	Standard errors	Coefficient	Standard errors
R&D Expenditure	0.00	0.00	-0.00	0.00
Lagged patent count	0.60***	0.19	0.85***	0.16
Year dummy (Policy Impact)	0.08**	0.03	0.01	0.01
	Adjusted R-squared = 0.83 Number of observation = 18		Adjusted R-squared = 0.61 Number of observation = 18	

Note: ***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The regulation period (the presence of the dioxin law) is 1997-2003. The regulation period for the recycling law is 1999-2008.

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Table 7. Patents related to environmental innovations

Patent Code group (IPC)	Short description of patent group
A62D	Chemical means for extinguishing fires or for combating or protecting against harmful chemical agents; chemical materials for use in breathing apparatus
B01D	Separation (separating solids from solids by wet methods BO3B, B03D by pneumatic jigs or tables B03B by other dry methods B07; magnetic or electrostatic
B03B	Separating solid materials using liquids or using pneumatic tables or jigs
B03C	Magnetic or electrostatic separation of solid materials from solid materials or fluids; separation by high-voltage electric fields
B03D	Flotation; differential sedimentation
B04B	Centrifuges
B04C	Apparatus using free vortex flow, e.g. cyclones
B07B	Separating solids from solids by sieving, screening, or sifting or by using gas currents; other separating by dry methods applicable to bulk
B07C	Postal sorting; sorting individual articles, or bulk material fit to be sorted piece-meal, e.g. by picking
B09	Disposal of solid waste; reclamation of contaminated soil
C02	Treatment of water, waste water, sewage or sludge
F01N	Gas-flow silencers or exhaust apparatus for machines or engines in general; gas-flow silencers or exhaust apparatus for internal-combustion engines
F02G	Hot-gas or combustion-product positive-displacement engine plants; use of waste heat of combustion engines, not otherwise provided for
F23C	Methods or apparatus for combustion using fluent fuel
F23D	Burners
F23G	Cremation furnaces; consuming waste by combustion
F23H	Grates (inlets for fluidisation air for fluidised bed combustion apparatus) cleaning or raking grates
F23J	Removal or treatment of combustion products or combustion residues; flues
F23K	Feeding fuel to combustion apparatus
F23L	Air supply; draught-inducing; supplying non-combustible liquid or gas
F23M	Constructional details of combustion chambers, not otherwise provided for
F23N	Regulating or controlling combustion

Note: IPC: International Patent Classification