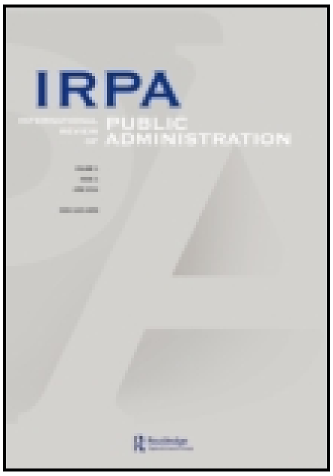

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Performance Tools and Their Impact on Pollution Reduction: an Assessment of Environmental Taxation and R&D

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PERFORMANCE TOOLS AND THEIR IMPACT ON POLLUTION REDUCTION: AN ASSESSMENT OF ENVIRONMENTAL TAXATION AND R&D*

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Although the theoretical implications of environmental taxation and government's research and development (R&D) investment have been discussed at length, a link between the effects of such tools and improved environmental performance has not been sufficiently supported by empirical evidence. This paper explores the effects of environmental taxation as well as R&D on environmental pollution. We used cross-country panel data from 26 OECD countries with observations ranging from 1995 to 2005. Our findings have led us to the conclusion that taxation has no significant effect on reducing environmental pollution, while governmental R&D expenditure exhibits a significant and positive impact on the reduction of environmental pollution.

Key Words: environmental taxation, environmental performance, R&D expenditures

INTRODUCTION

Worldwide recognition of climate change, which has now firmly been linked to greenhouse gas emissions, has led countries to consider implementing regulations, taxes, and subsidies for technological innovation that are geared towards curbing these emissions (Bruvoll & Larsen, 2004). Beginning in the 1980s, governments around the world, and in particular OECD members, began to focus their attention on refining their environmental policymaking and governance systems due to the growing demands for improved environmental quality. As a consequence, policymakers were forced to take into consideration the environmental impact of their choices when formulating their nations' economic policies. However, the environmental authorities of the governments faced so-called state failures (Janicke, 1990) with regard to their environmental governance efforts and thus decided to shift from purely state-led forms of environmental governance to more market-based instruments. A clear product of this innovative approach was a stronger reliance on environmental taxes.

Among the many policy tools for reducing pollution, environmental taxes have been favored by a majority of the OECD countries. The "polluter pays" principle of environmental taxation, which can be considered as a product of such a policy approach, was embodied by the 16th principle outlined in the Rio Declaration on Environment and Development (1992): "National authorities should endeavor to promote internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and environment." This statement acknowledges that pollution cannot be disposed of cost-free and hence some productive resources must be sacrificed if levels of polluting emissions are to be reduced (Zaim & Taskin, 2000).

Although the economic implications of environmental taxation have been well discussed in a variety of approaches, a clear link between the effects of taxation and reduction of environmental pollution has not been sufficiently supported by empirical records. In particular, there has been a notable lack of empirical cross-country analyses of the effects of environmental taxation as well as other alternative policies. The Rio Declaration states, "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." At this point it is necessary to begin considering what exactly the terms "cost-effective measures" and "effective measures" refer to in order to avoid forming a hasty and largely arbitrary conclusion that taxation will bring about tangible changes to environmental performance; if such a conclusion is to be reached, it must be firmly based on reliable evidence.

This article seeks to examine the effect of environmental taxation on the reduction of greenhouse gas emissions based on data collected from 26 OECD countries from 1995 to 2005. In addition, we will also test the alternative policy solution of increased environmental R&D, which has been less discussed but could in fact have a vital impact on environmental performance. In judging the performance of environmental policy instruments, it is critically important to consider the extent to which policy instruments induce new technology that can efficiently conserve the environment (Kneese, et al., 1975), but there is still little empirical evidence of the effectiveness of governmental R&D investment. Therefore, we believe that these empirical exercises can contribute to our knowledge of this matter.

ENVIRONMENTAL TAXATION OR R&D INVESTMENT

Environmental Taxation

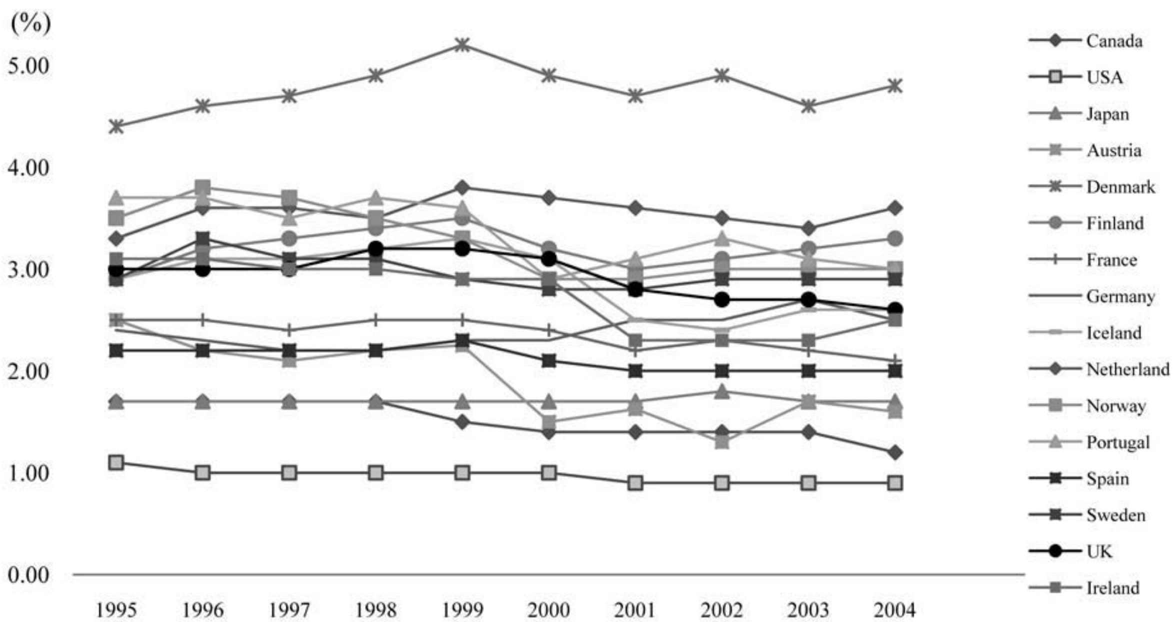
Taxation as an instrument of environmental policy has received widespread support from much of the economically driven literature (Baumol & Oates, 1988; Coase, 1960; Dales, 2002; Dewees, 1983; Kim, 2003; Kneese, Schultze, & Institution, 1975; DW Pearce & Turner, 1990; Pigou & Aslanbeigui, 2001) and as a consequence, this tool, which had previously existed only in theory until the 1960s, began in the 1980s to be used as an innovative strategy for managing environmental problems (Hahn, 1989). Taxation tools such as emissions charges represent a means for inducing businesses to search for lower cost methods of achieving environmental standards. This stands in stark contrast to the predominant "command-and-control" approach, in which a regulator specifies the technology a firm must use in order to comply with regulations. Under highly restrictive conditions, it is possible to see how both of these economic approaches share the desirable feature of matching environmental quality gains to the lowest possible costs in the pursuit of improved environmental performance (Baumol & Oates, 1988).

Environmental taxes are one of the most popular policy tools in many countries. A tax on externality-creating behavior is believed to improve resource allocation and also raise revenue that can be used to reduce distortions elsewhere (Acutt & Dodgson, 1996), which is called the double-dividend effect (Goulder, 1995). In this manner, a pollution tax is often used as an effective policy instrument.

Countries such as Norway, Sweden, Finland, the Netherlands, and France have implemented emissions taxes for various pollutants, in particular sulfur dioxide (SO_2) and nitrogen oxide (NO_x) (Requate, 2005). Targeting CO_2 emissions, Denmark, Germany, and the Netherlands charge taxes on energy, while the United States was the first to introduce markets for pollution permits on a large scale, notably for SO_2 and NO_x. And recently the European Union launched a directive for CO_2 permit trading in Europe. Figure 1 presents the percentage of GDP formed by environmental taxes in some major OECD countries.

As we can see from Figure 1, Demark has the highest level of environmental taxes as a percentage of GDP, around 4% to 5%, while the United States has the lowest level, typically no more than 1%. Countries such as Germany, France, and U.K. fall somewhere in the middle of the OECD member-nations, with environmental taxes at around 3% of GDP. When we look at the time-series variations, we realize that some countries, such as Norway, Ireland, and Austria, have decreased the level of environmental taxes, while no

Figure 1. Environmental Taxes as a Proportion of GDP in Major Countries (1995–2005)



Source: OECD

country demonstrates a continuing increase.

Environmental R&D Investment from Government

One of the most important criteria on which to judge the performance of environmental policy instruments is the extent to which they spur new technology aimed at the efficient conservation of the environment (Kneese, et al., 1975;Wang & Huang, 2007). But how to co-ordinate the dynamic technological effects of environmental policy with the environmental effects of innovation policy is one of the biggest challenges faced by governments today (Heaton, 2000). A general prescription that has significant potential is to embed innovation policy in environmental policy by gearing policy instruments towards technologies that will offer a source of potential environmental protection and remediation (OECD, 2000). Dechamps and Pilavachi (2004) analyzed the R&D initiatives of the European Commission (EC) for the purpose of mitigating CO_2 emissions and assert that, as there is increasing concern regarding climate change issues related to greenhouse gas emissions worldwide, not only reducing the use of fossil fuels but also introducing new techniques is required to reduce CO_2 emissions. According to the authors, further investment in R&D to decrease CO_2 emissions is worthwhile, as the cost required to reduce CO_2 emissions depends on air purification techniques. Moreover, considerable R&D effort is required to implement a sustainable energy system in order to ensure an impact in the medium to long term (Dechamps & Pilavachi, 2004).

And issues of environmental R&D are interconnected with energy use and innovation in energy sector technologies. Most countries share the assumption that greater energy efficiency will carry them a significant part of the way toward realizing major carbon emissions reductions in the future, despite their differences in political culture and choice of policy instruments (Dooley & Runci, 1999). Thus, R&D investment in advanced energy technology programs is needed to diminish CO_2 concentration. Dooley and Runci (1999) present findings from a study of major OECD nations' changes in R&D investment portfolios related to energy and global climate change, concluding that the level of investment in energy R&D in the OECD is insufficient to meet the current needs. Nine OECD countries at one point made up more than 95% of the world's public sector R&D that related to environmental technologies or energy, but these nations reduced their budget for energy R&D on average by more than 20% between 1985 and 1995, and are showing a downward trend (Dooley & Runci, 1999). Exemplary of this trend are Germany, Italy, and the United Kingdom, in which the budgets for clean energy R&D were cut by 70% or more over the same period. From this point of view, each country's present level of R&D investment is insufficient to meet the challenge of reducing greenhouse emissions.

And government investments or subsidies for R&D are an important element of policies aimed at environmental technology (Kemp, 2000b). The Danish Clean Technology Development Program experienced positive results from government investment in environmental R&D programs (Georg, Ropke, & Jorgensen, 1992). Under the program, semi-governmental research institutions and private firms were able to apply for financial aid for developing and implementing clean technology, and the program stimulated preventive process solutions and co-operation among technology suppliers, research institutions, consultancy firms and users (OECD, 2000). The Danish Environmental Protection Agency played an active role in selecting environmentally beneficial projects and finding the right partner with a solution, (Kemp, 2000a). The Danish program was a success, as appropriate technical solutions were found for environmental problems in almost all cases and substantial environmental improvements were achieved at low cost in more than half of the projects.

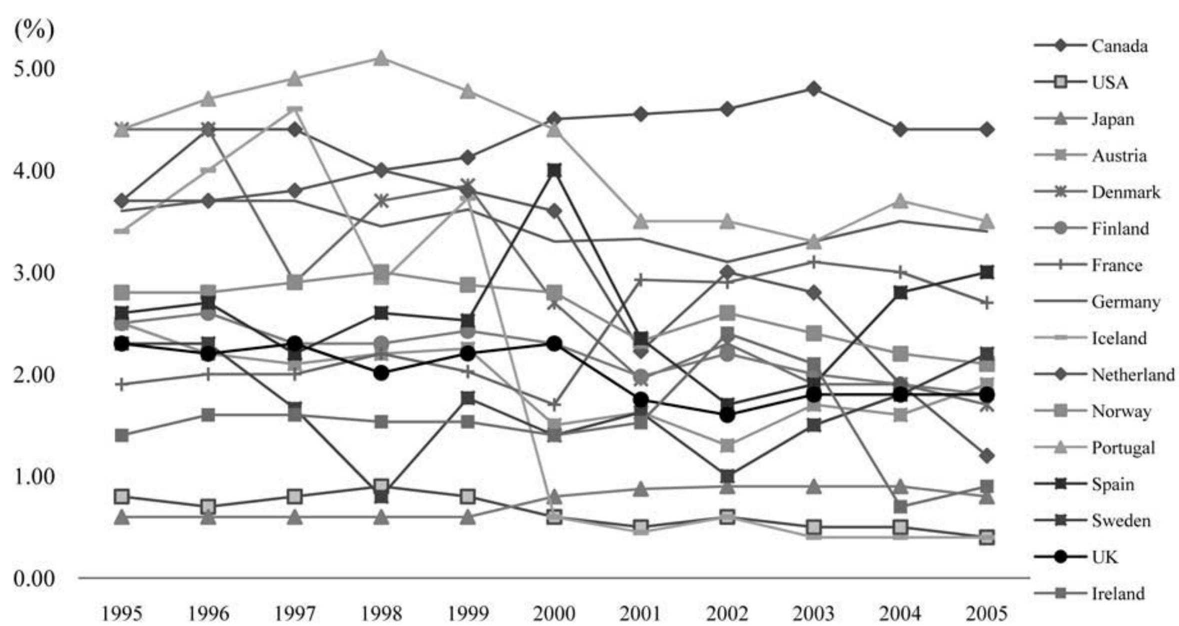
Figure 2 depicts some major OECD countries' governmental efforts in environmental R&D as a proportion of total R&D expenditures. As shown in Figure 2, Canada and Portugal have the highest level of environmental R&D expenditure, although Portugal has experienced sharp drops since 1998 while Canada has steadily increased it.

In terms of environmental R&D efforts, the United States also shows the lowest ratio of expenditure to GDP. Japan and Iceland have a very low level of investment, and Iceland especially shows a considerable decline since 2000. France and the U.K. show an intermediate level of R&D investment.

EMPIRICAL STUDIES ON PERFORMANCE OF ENVIRONMENTAL GOVERNANCE

A considerable number of empirical studies on

Figure 2. Environmental R&D Expenditure as a Proportion of Total R&D in Major Countries (1995–2005)



Source: OECD(%)

environmental performance have been conducted and these studies can be divided into two categories: those measuring environmental performance and those that investigate factors affecting environmental performance.

Measuring Performance of Environmental Governance

"Environmental performance" has become a concept widely advocated and quoted by environmental decision makers and policy analysts (Zhou, Ang, & Poh, 2008). Consequently, the aggregated environmental performance index (EPI) has evolved as a key measurement in environmental systems analysis. Development of EPIs can be categorized into data-driven and theory-driven strands (Niemeijer, 2002), and the techniques for constructing aggregated EPIs can further be divided into indirect and direct approaches. In the indirect data set, such as the environmental sustainability index, the key economic, energy, and environmental sub-indicators are identified and then normalized and integrated into an overall index with weighting and aggregating techniques (Esty, Levy, Srebotnjak, & De Sherbinin, 2005). On the other hand, the direct data setapproach directly obtains an aggregated EPI from the observed quantities of the inputs and outputs of the environmental system using a nonparametric approach called DEA (Zhou, et al., 2008).

There are a great number of studies on both the definition and measurement of environmental performance (Chung, Kang, & Lee, 2008). These studies have thus far either drawn from an existing performance index or created their own using a model of certain environmental factors. Chung et al. (2008), for instance, estimate efficiency and loss of productivity under environmental regulation, and analyze the environmental efficiency index of the OECD. Others see sustainability as a key factor in environmental performance. Siche et al. (2008) use a total of three sustainability indices: Ecological Footprint (EF), Environmental Sustainability Index (ESI), and Energy Performance Indices (EPIs) to make a comparison between fourteen nations (Siche, Agostinho, Ortega, & Romeiro, 2008). As a criterion of environmental performance measurement the OECD uses "decoupling," which is divided into absolute decoupling and relative decoupling. Decoupling separates environmental pollution from economic growth.

One thing common to most of these diverse approaches to the measurement of environmental performance is that greenhouse gas emissions, especially CO2 emissions, were used as the main criterion (Andersen, 2005; Cortazar, Schwartz, & Salinas, 1998; Cracolici, Cuffaro, & Nijkamp, 2010; Jung & Chung, 2004; Verbeke & Coeck, 1997; Zofio & Prieto, 2001). Therefore, this study used greenhouse gas emissions as a proxy for the overall environmental performance of a country.

Determinants of Environmental Performance

According to literature that is mostly economics driven or based on findings from specific cases, factors such as a carbon tax, R&D, and economic growth are expected to have a significant effect on CO_2 emissions reduction. Because countries have been obligated to reduce future greenhouse gas emissions according to the Framework Convention on Climate Change, it is emphasized that the development and introduction of effective policy tools for minimizing cost and reducing greenhouse gas emissions are important. There are policy tools such as emissions trade, carbon tax (environmental taxes), subsidies, and voluntary agreement, of which the most widely used is the carbon tax (Borchiellini, Massardo, & Santarelli, 2010; Bristow, Wardman, Zanni, & Chintakayala, 2010; Metcalf, 2009; Metcalf & Weisbach, 2009; D Pearce, 1991; Shin, 2000). Shin (2000), Anderson (2005), and Bruvoll and Larson (2004) suggest that the introduction of a carbon tax reduces carbon dioxide emissions, while others claim that emissions trade is more effective than carbon tax in reducing greenhouse gas emissions (Ermolieva, Ermoliev, Fischer, Jonas, & Makowski, 2010; Malueg, 1989; Manne & Richels, 1997).

Shin (2000) explores the effect of a carbon tax on CO_2 reduction in Korea. He argues that a levy of US$10 per produced unit causes around 6% CO_2 reduction when there are scale economies and around 3% reduction without scale economies. Anderson (2005) posits that Denmark's industry reduced CO_2 emissions by 25% per produced unit between 1993 and 2000 as a result of CO_2 taxes. Furthermore, he notes that carbon energy taxes can be introduced without a negative effect on industry competitiveness by lowering energy cost per unit, again drawing on the Danish example of reduced energy consumption. In a similar example, Bruvoll and Larson (2004) note that Norway introduced a relatively high carbon tax, and, although total emissions have increased, there has been a significant reduction in emissions as a percentage of GDP: 2.3% per unit of GDP. In addition, Hofer, Dresner, and Windle (2010) suggest that airline emissions taxes on the aggregate U.S. domestic market may cause a decrease in carbon emissions. They point out that carbon emissions by the U.S. domestic airline industry have decreased by over 5 billion pounds per year as a result of a 2% tax.

These examples show that a carbon tax is one of the key variables affecting environmental performance and must not be excluded from any comprehensive model.

On the other hand, a great number of studies find that economic growth has a significant effect on environmental performance. Jung and Chung (2004) and Zaim and Taskin (2000) try to identify a causal relationship between environmental pollution and national income. They found that environmental pollution (CO_2 emissions) consistently worsened as GDP increased, a result which corresponds to the environmental Kuznets curve's (EKC) inverted U shape. Yet Kim (2003) estimates that a nation's economic growth has neither a significant positive nor negative impact on CO_2 emissions as a pollution factor.

Though many studies concentrate on the factors that influence environmental quality, few have attempted to draw upon empirical evidence in order to estimate the causal relationship between environmental performance and actual influencing factors. Those that do identify a causal relationship still tend to focus on time-series studies such as searching trends in CO_2 emissions over a period of time. In addition, neither analysis using panel data nor comparative country studies have been undertaken, gaps in the current research which make it difficult to generalize any conclusions that are reached. Lastly, it is necessary to evaluate the success of various policy tools, such as R&D investment, in order to increase overall environmental performance ratings.

Although there are several studies that focus on the effect of taxes and R&D investment on CO_2 emissions or greenhouse gas emissions as described above, there still remains a substantial need to identify real causal relationships based on cross-country empirical findings. Therefore, we will here employ empirical data when formulating the standards and measurements by which environmental performance can be judged.

ANALYTIC FRAMEWORK

Dependent Variable: Environmental Performance

This paper will investigate the effects of various factors on environmental performance, and henceforth we will use environmental performance, as measured by greenhouse gas emissions, as a dependent variable. Some literature rates environmental sustainability or the compatibility between economic growth and environmental factors as the primary factor in environmental performance (Siche et al., 2008). Nevertheless, environmental performance is essentially related to enhancing the quality of the environment, so raising environmental quality by reducing environmental pollution will positively affect environmental performance. Consequently, while we do consider the reduction of environmental pollution as a goal in improving the overall quality of the environment, we focus on air pollution as the factor most relevant to the planet as a whole. Most of the cross-country comparative research dealing with air pollution uses CO_2 or greenhouse gas as a factor (Andersen, 2005; Jung & Chung, 2004; Zofio & Prieto, 2001). While substances such as carbon dioxide, methane, nitrogen dioxide, Freon and so on do contribute to global warming, it is carbon dioxide which accounts for the largest percentage of dangerous emissions (Jung & Chung, 2004). However, in this paper, we will use greenhouse gas emissions, which include CO_2, sulfur dioxide (SOX), and nitric oxirogen, as a proxy of environmental performance, in order to produce a more sophisticated performance measurement. In this connection, the OECD (2008) uses CO_2 emissions with greenhouse gas emissions to measure climate change as a part of its Key Environmental Index (OECD, 2008).

Independent Variables: R&D and Tax

We used public R&D budgets for control and care of the environment as a percentage of total R&D budget appropriations. The data were obtained from the OECD and measure spending on pollution control research by identifying and analyzing the sources and causes of pollution, including dispersal into the environment and effects on humans, animals, and the biosphere. These funds were also used for the development of monitoring facilities for all kinds of pollutants.

In this paper, we define carbon tax as any environment-related tax, including all compulsory, unrequited payments levied by government on tax bases deemed to be of particular environmental relevance. Environmentally relevant tax bases include energy products, motor vehicles and transportation, waste management, ozone depleting substances, and others. We used OECD data on revenues from environment-related taxes. Revenue is raised from individual tax bases in millions of U.S. dollars.

Control Variables

It is essential to control for other variables in order to see the unique effect of environmental tax and R&D on environmental performance. First, we should consider a country's per capita income and economic growth rate. To do this, the OECD uses the decoupling concept to measure environmental performance for member countries and distinguishes between absolute and relative decoupling. Decoupling occurs when economic growth takes place without environmental pollution. When a country's GDP is growing while the environmentally relevant variable is stable or decreasing, it is defined as absolute decoupling (Andersen, 2005). Relative decoupling is said to occur when the growth rate of the environmentally relevant variable is positive, but less than the growth rate of the economic variables. Therefore, it is necessary to include per capita income in our model and to control for its effect. On the other hand, per capita income shows the situation of a country's economy at a certain point, but the degree of pollution varies depending on the nation's growth rate. Thus, we also control for the economic growth rate, as this has a larger impact on environmental performance. We used GDP data from World Development Indicators (WDI).

Second, we consider the degree of urbanization. Although many preceding studies have found that economic growth directly affects CO_2 emissions, it is more reasonable to suppose that, rather than there being a direct relationship between economic growth and CO_2

Table 1. Variables

Variable	Measure	Unit
greenhouse gas	greenhouse gas emissions annual variation rate	%
R&D	public research & development expenditure for environmental protection (as % of total R&D budget appropriations)	%
taxation	environmentally related taxes (as % of GDP)	%
per capita income	GDP per capita	USD
economic growth	annual GDP growth rate	%
urbanization	IMD urbanization index	1-10
manufacturing	annual variation of manufacturing production	%

Table 2. Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.
greenhouse gas	0.21	1.60	-0.98	16.6
R&D	2.38	1.20	0.10	5.10
taxation	2.63	0.82	0.90	5.20
per capita income	21693.54	11931.97	2,246.30	54974.20
economic growth	2.58	2.85	-6.34	26.08
urbanization	5.77	1.36	0.00	8.69
manufacturing	2.576	3.60	-7.57	17.46

emissions, economic growth instead causes industrialization and urbanization, during the process of which CO_2 emissions increase and environmental pollution worsens. Thus, to further clarify this supposition, we need also to look at the degree of urbanization and its impact on environmental performance. For this purpose, we used 2005 urbanization data from an IMD opinion survey of CEOs in various countries. In the same vein, we controlled for manufacturing production by using indices of industrial production (IIP) for the manufacturing industry from OECD's MEI dataset.

Table 1 and Table 2 describe the measurement and characteristics of the variables.

Econometric Model

To test the relationship between the greenhouse gas emission rate and independent variables, we used time-series cross-sectional regressions. These regressions make use of panel datasets that consist of time-series measurements on each of the cross-sectional observations. Panel data were used in this study is because they reveal the dynamic reactions of each subject, create variability, and provide more informative results while obviating the need for lengthy time-series observations (Frees, 2004; Gujarati, 2003; Kennedy, 2003; Wooldridge, 2002).

Due to the spatial and temporal characteristics of panel data, the use of ordinary least squares (OLS) regression can bias results, therefore we have chosen to use a fixed effects model instead (Baltagi & Boozer, 1997; Beck & Katz, 1995; Bhargava, Franzini, & Narendranathan, 1982; Oatley, 1999). While no single technique can guarantee the elimination of all econometric problems, we can avoid several major problems by making use of the fixed effects model instead of OLS. The fixed-effects model is preferable to OLS because it offers the advantage of holding constant any unobserved (omitted) country-specific (time-invariant) determinants of the dependent variable (Beck & Katz, 1995; Persson & Tabellini, 2005). In addition, the fixed effects model computes estimates based on differences in variables within countries across time, under the assumption that individual effects are correlated over time, but are unrelated to any other regressors (Arellano & Honore, 2001; Plumper & Troeger, 2007). Consequently this model can correct for problems related to endogeneity (Semykina & Wooldridge, 2005).

We employed a method used by Wansbeek and Kapteyn (1989) to handle the missing observations. This estimation of the variance components is performed by using a quadratic unbiased estimation (QUE) method that involves focusing on quadratic forms of the residuals, equating their expected values to the realized quadratic forms, and solving for the variance components (Wansbeek & Kapteyn, 1989). The estimated generalized least squares procedure substitutes the QUE estimates into the covariance matrix of the composite error term.

RESULTS AND DISCUSSION

Table 3 presents the results of the regression. The results show that R&D has a significant and negative relationship with greenhouse gas emissions at the 0.001 level in Model 1 and 0.01 level in Model 2. This means that R&D investment can be a useful policy tool for reducing greenhouse gas emissions. And in Model 3 and in Model 4, where we consider the time lag of the R&D investment, the one year lagged variable of R&D expenditure is negatively associated with greenhouse gas emissions at the 0.001 level in Model 3 and at the 0.01 level in Model 4. This supports more strongly our prediction that R&D causes a reduction in greenhouse gas emissions. On the other hand, taxation, which is widely believed to have a positive impact, shows no significant relationship with the level of greenhouse gas emissions in these four models. The remaining variables all have a non-significant relationship with greenhouse gas emissions.

It is easy to understand why R&D has this positive effect on environmental performance. Because a multitude of environmental problems are associated with production facilities, technologies designed to reduce the environmental impact of production facilities can have a tangible effect. However, these technologies require a substantial amount of investment from the firm, which increases operating costs and reduces the maximum production level (Cortazar et al., 1998). In other words, pollution-reducing investments have a negative impact on a firm's economic performance, as the investments are in nonproductive assets with no monetary benefit to the firm (Conrad & Morrison, 1989; Gray, 1987). Therefore, if government, rather than individual firms, invests in the development of these environmental technologies, this will help reduce the

Table 3. TSCS Regression Results

	Model 1	Model 2	Model 3	Model 4
constant	-2.132 (2.135)	2.248 (1.808)	-2.148 (3.250)	4.516 (2.885)
taxation	0.790 (0.633)		1.139 (1.009)	
taxation (t-1)		-0.595 (0.445)		-1.395 (0.713)
R&D	-0.169*** (0.039)	-0.114** (0.037)		
R&D (t-1)			-0.199***	-0.113** (0.049) (0.046)
per capita income	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
economic growth	0.005 (0.047)	0.009 (0.046)	-0.048 (0.072)	0.006 (0.069)
urbanization	-0.027 (0.129)	0.049 (0.118)	-0.323 (0.260)	0.033 (0.228)
manufacturing	0.008 (0.016)	-0.006 (0.013)	0.018 (0.028)	-0.009 (0.021)
F test for non-fixed effects	2.04	1.20	2.27	1.11
Hausman test for random effects	13.86	14.32	16.29	5.47
R-squared	0.198	0.090	0.269	0.107
Time Series	1995–2005			
Number of Countries	26			

Note: Statistically significant at * p<0.05 ** p<0.01 *** p<0.001

country's total environmental pollution level. Technologies appropriate for investment are manifold and include production equipment, methods and procedures, product design, product delivery mechanisms that minimize the environmental load of human activities and protect the natural environment, and pollution control equipment, ecological measurement instrumentation, and cleaner production technologies (Shrivastava, 1995).

To explain the result of the insignificant relationship between taxation and environmental pollution would be complicated. One possible explanation could be found in the division of the short-term and dynamic effects of environmental taxation suggested by Verbeke and Coeck (1997). In the short run, firms will primarily create cost effects, and in the medium run, investments will reduce pollution levels: this is the "short-term effect." However, these positive behavioral effects also imply a reduction in the government's financial resources from environmental taxation. The conflict between the pollution-reduction objectives and the financial objectives of the government may generate a number of unintended effects on the firms' behavior, which we can call the "dynamic effect."

To remedy this, public policy makers could increase environmental tax levels or continuously introduce new taxes in order to stabilize the volume of financial resources that have been reduced by positive behavioral effects. Consequently, higher tax levels will push firms toward further reductions in pollution levels, which in turn will lead to a further decline in the government's financial resources. The important point is how top executives at corporations perceive these taxes. The credibility of environmental policy will decline if the increased tax levels become viewed as an unfair system used primarily to redistribute resources from firms to the government. If the increasing taxation is perceived as an arbitrary measure to stabilize government income, evasive behavior by the firms may be induced; for example, firms may attempt to engage in environmental tax avoidance or evasion, which may include the relocation of production facilities. In other words, this vicious cycle of environmental taxation could create a situation whereby the environmental tax level is continuously increasing and new taxes are constantly being introduced, while the actual external effect of pollution reduction is weakened by the behavior of firms.

CONCLUSION

In this article, we have explored the various levels of success of different environmental policy tools. Previous studies have shown that environmental taxation is the most popular tool and that it led to a decrease in CO_2 or greenhouse gas emissions. In contrast, we concluded that R&D investment has a significant effect on greenhouse gas emissions reduction, while environmental taxation has no significant effect. This result contradicts the recent trend of countries levying a carbon tax on industries in order to meet greenhouse gas reduction levels agreed upon at the Convention on Climate Change. This surprising result can be explained by Verbeke and Coeck's (1997) analysis: introducing new taxes in order to stabilize the volume of financial resources will ultimately lead to evasive maneuvers on the part of corporations. Thus, it is our recommendation to increase the percentage of environmental improvement budgets devoted to R&D funding.

The significance of our study lies in its utilization of leading research that empirically investigates environmental performance using panel data sets and cross-country analysis. But there is more work to be done. Future research should use multiple measures and approaches in order to arrive at a more sophisticated model and to determine the variables that could influence and control greenhouse gas emissions.

NOTE

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REFERENCES

Acutt, M., & Dodgson, J. (1996). Policy instruments and greenhouse gas emissions from transport in the UK. ***Fiscal Studies***, ***17***(2), 65–82.

Andersen, M. (2005). Decoupling environmental pressures and cconomic growth. ***Public Policy Research***, ***12***(2), 79–84.

Arellano, M., & Honore, B. (2001). Panel data models: Some recent developments. ***Handbook of Econometrics***, ***5***, 3229–3296.

Baltagi, B., & Boozer, M. (1997). Econometric analysis of panel data. ***Econometric Theory***, ***13***(05), 747–754.

Baumol, W., & Oates, W. (1988). ***The theory of environmental policy***. Cambridge University Press.

Beck, N., & Katz, J. (1995). What to do (and not to do) with time-series cross-section data in comparative politics. ***American Political Science Review***, ***89***(3), 634–647.

Bhargava, A., Franzini, L., & Narendranathan, W. (1982). Serial correlation and the fixed effects model. ***The Review of Economic Studies***, ***49***(4), 533–549.

Borchiellini, R., Massardo, A., & Santarelli, M. (2010). A carbon exergy tax evaluation based on the efficient use of energy resources: A case study. ***International Journal of Thermodynamics***, ***3***(3), 129.

Bristow, A., Wardman, M., Zanni, A., & Chintakayala, P. (2010). Public acceptability of personal carbon trading and carbon tax. ***Ecological Economics***.

Bruvoll, A., & Larsen, B. (2004). Greenhouse gas emissions in Norway: Do carbon taxes work? ***Energy Policy***, ***32***(4), 493–505.

Chung, Y., Kang, S., & Lee, J. (2008). Comparative analysis of OECD countries based on the environment-economy efficiency. ***Environment and Resource Economic Review***, ***17***(1), 121–146.

Coase, R. (1960). The problem of social cost. ***Journal of Law and Economics***, ***3***, 1–44.

Conrad, K., & Morrison, C. (1989). The impact of pollution abatement investment on productivity change: an empirical comparison of the U.S., Germany, and Canada. ***Southern Economic Journal***, 55(3), 684–698.

Cortazar, G., Schwartz, E., & Salinas, M. (1998). Evaluating environmental investments: A real options approach. ***Management Science***, ***44***(8), 1059–1070.

Cracolici, M., Cuffaro, M., & Nijkamp, P. (2010). The measurement of economic, social and environmental performance of countries: A novel approach. ***Social Indicators Research***, ***95***(2), 339–356.

Dales, J. (2002). ***Pollution, property & prices: An essay in policy-making and economics***. Cheltenham: Edward Elgar Pub.

Dechamps, P., & Pilavachi, P. (2004). Research and development actions to reduce CO_2 emissions within the European Union. ***Oil & Gas Science and Technology***, ***59***(3), 323–330.

Dewees, D. (1983). Instrument choice in environmental policy. ***Economic Inquiry***, ***21***(1), 53–71.

Dooley, J., & Runci, P. (1999). ***Adopting a long view to energy R&D and global climate change***. Pacific Northwest National Laboratory.

Ermolieva, T., Ermoliev, Y., Fischer, G., Jonas, M., & Makowski, M. (2010). Cost effective and environmentally safe emission trading under uncertainty. ***Coping with Uncertainty***, 79–99.

Esty, D., Levy, M., Srebotnjak, T., & De Sherbinin, A. (2005). Environmental sustainability index: Benchmarking national environmental stewardship. ***New Haven: Yale Center for Environmental Law & Policy***.

Frees, E. (2004). ***Longitudinal and panel data: Analysis and applications in the social sciences***. Cambridge University Press.

Georg, S., Ropke, I., & Jorgensen, U. (1992). Clean technology: Innovation and environmental regulation. ***Environmental and Resource Economics***, ***2***(6), 533–550.

Goulder, L. (1995). Environmental taxation and the double dividend: A reader's guide. ***International Tax and Public Finance***, ***2***(2), 157–183.

Gray, W. (1987). The cost of regulation: OSHA, EPA and the productivity slowdown. ***The American Economic Review***, ***77***(5), 998–1006.

Gujarati, D. (2003). Basic econometrics. New York, NY: McGraw-Hill.

Hahn, R. (1989). Economic prescriptions for environmental problems: How the patient followed the doctor's orders. ***The Journal of Economic Perspectives***, ***3***(2), 95–114.

Heaton, G. (2000). Workshop on innovation and the environment: Rapporteur's report. In OECD (Ed.), ***Innovation and the environment***. Paris: OECD publications.

Hofer, C., Dresner, M., & Windle, R. (2010). The environmental effects of airline carbon emissions taxation in the U.S. ***Transportation Research Part D: Transport and Environment, 15***(1), 37–45.

Janicke, M. (1990). ***State failure: The impotence of politics in industrial society***. University Park: Pennsylvania State University Press.

Jung, K., & Chung, Y. (2004). The pollution and economic growth based on the multi-country comparative analysis. ***Industrial Economics Research***, ***17***(4), 1077–1098.

Kemp, R. (2000a). Technological and environmental policy: Innovation effects of past policies and suggestions for iprpment. In OECD (Ed.), ***Innovation and the Environment***. Paris: OECD publications.

______. (2000b). Technology and environmental policy: Innovation effects of past policies and suggestions for improvement. ***Innovation and the Environment***, 35–61.

Kennedy, P. (2003). ***A guide to econometrics***. Cambridge, MA: The MIT Press.

Kim, J. (2003). A study on relationship between economic growth and pollution: Theoretical and empirical analysis. ***Environment and Resource Economic Review***, ***2***(3), 515–529.

Kneese, A., Schultze, C., & Institution, B. (1975). ***Pollution, prices, and public policy:*** Washington, D.C.: The Brookings Institution.

Malueg, D. (1989). Emission credit trading and the incentive to adopt new pollution abatement technology. ***Journal of Environmental Economics and Management***, ***16***(1), 52–57.

Manne, A., & Richels, R. (1997). On stabilizing CO_2 concentrations: Cost effective emission reduction strategies. ***Environmental Modeling and Assessment***, ***2***(4), 251–265.

Metcalf, G. (2009). Designing a carbon tax to reduce U.S. greenhouse gas emissions. ***Review of Environmental Economics and Policy***.

Metcalf, G., & Weisbach, D. (2009). The design of a carbon tax. ***Harvard Environmental Law Review***, ***33***(2), 499–556.

Niemeijer, D. (2002). Developing indicators for environmental policy: Data-driven and theory-driven approaches examined by example. ***Environmental Science & Policy***, ***5***(2), 91–103.

Oatley, T. (1999). Central bank independence and inflation: Corporatism, partisanship, and alternative indices of central bank independence. ***Public Choice***, ***98***(3), 399–413.

OECD. (2000). ***Inovation and the Environment***. Paris: OECD publications.

______. (2008). ***Key Environmental Indicators***. Paris: OECD publications.

Pearce, D. (1991). The role of carbon taxes in adjusting to global warming. ***The Economic Journal***, ***101***(407), 938–948.

Pearce, D., & Turner, R. (1990). Economics of natural resources and the environment, Hemel Hempstead: Harvester Wheatsheaf. ***Perman, R., Ma, Y., McGilvray, J. and Common, M.(2003) Natural Resource and Environmental Economics. 3rd edition, Longman***.

Persson, T., & Tabellini, G. (2005). ***The economic effects of constitutions***. Cambridge, MA: The MIT Press.

Pigou, A., & Aslanbeigui, N. (2001). ***The economics of welfare***. Transaction Publishers.

Plumper, T., & Troeger, V. (2007). Efficient estimation of time-invariant and rarely changing variables in finite sample panel analyses with unit fixed effects. ***Political Analysis, 15***(2), 124.

Requate, T. (2005). Dynamic incentives by environmental policy instruments: A survey. ***Ecological Economics***, ***54***(2-3), 175–195.

Semykina, A., & Wooldridge, J. (2005). ***Estimating panel data models in the presence of endogeneity and selection: Theory and application***. Ann Arbor: Michigan State University.

Shin, D. (2000). Scale economics and the effects of a carbon tax on Korean economy: A Cournot-Walrasian CGE simulation. ***Environment and Resource Economic Review, 9***(5), 973–997.

Shrivastava, P. (1995). Environmental technologies and competitive advantage. ***Strategic Management Journal, 16***(S1), 183–200.

Siche, J., Agostinho, F., Ortega, E., & Romeiro, A. (2008). Sustainability of nations by indices: Comparative study between environmental sustainability index, ecological footprint and the emergy performance indices. ***Ecological Economics, 66***(4), 628–637.

Verbeke, A., & Coeck, C. (1997). Environmental taxation: A green stick or a green carrot for corporate social performance? ***Managerial and Decision Economics, 18***(6), 507–516.

Wang, E., & Huang, W. (2007). Relative efficiency of R&D activities: A cross-country study accounting for environmental factors in the DEA approach. ***Research Policy, 36***(2), 260–273.

Wansbeek, T., & Kapteyn, A. (1989). Estimation of the error-components model with incomplete panels. ***Journal of Econometrics, 41***(3), 341–361.

Wooldridge, J. (2002). ***Econometric analysis of cross section and panel data***. Cambridge, MA: The MIT press.

Zaim, O., & Taskin, F. (2000). Environmental efficiency in carbon dioxide emissions in the OECD: A non-parametric approach. ***Journal of Environmental Management, 58***(2), 95–107.

Zhou, P., Ang, B., & Poh, K. (2008). Measuring environmental performance under different environmental DEA technologies. ***Energy Economics, 30***(1), 1–14.

Zofio, J., & Prieto, A. (2001). Environmental efficiency and regulatory standards: The case of CO_2 emissions from OECD industries. ***Resource and Energy Economics, 23***(1), 63–83.

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