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Examining the Dynamic Effects of Eco-Innovation on the Exports of Environmentally-Friendly Products†

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ABSTRACT : This study examines how eco-innovation contributes to the exports of environmentally-friendly products using the dynamic panel model. The results reveal that the adjustment in the exports exists to recover the long-run equilibrium with sluggish adjustment speed. In addition, the results show that environmental patent applications and environment-related R&D expenditures are beneficial for enhancing the environmentally-friendly exports. While the environmental patent applications are associated only with an increase in the exports of products for resource management, the environmental R&D expenditures contribute to the exports of pollution management products, cleaner technologies and products, and resource management products. Moreover, as the long-run effects of eco-innovation on the exports become greater than the short-run effects, it appears that public eco-innovation is more likely to support future exports than private eco-innovation.

Keywords : Eco-innovation, Environmentally-friendly exports, Patent, R&D, Dynamic panel model

JEL Classification : F18, Q55

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환경혁신이 환경친화적 수출에 미치는 동태적 영향 분석†

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요 약 : 본 연구는 환경혁신이 환경친화적 제품의 수출에 미치는 영향을 동태패널모형을 이용하여 분석한다. 분석결과 환경친화적 제품의 수출은 장기 균형에 느리게 수렴하는 동태적 조정과정이 있는 것으로 분석되었다. 또한 환경혁신으로 대표되는 환경 부문의 민간 특허와 환경 관련 공공 R&D 지출의 경우 환경친화적 수출에 긍정적인 효과가 있는 것으로 나타났다. 구체적으로 환경친화적 제품은 자원 관리, 오염 관리, 청정 기술 부문의 제품으로 분류되어 있는데, 특허의 경우 자원 관리 부문의 수출에, R&D 지출의 경우 모든 부문의 수출에 기여하는 것으로 나타났다. 동태효과에 대한 추정결과 환경혁신의 수출 증진 효과는 장기로 갈수록 크게 나타났으며, 공공 부문의 환경혁신이 민간 부문의 환경혁신에 비해 수출에 더 크게 기여하는 것으로 나타났다.

주제어 : 환경혁신, 환경친화적 수출, 특허권, R&D, 동태패널모형

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Ⅰ. Introduction

According to the Organization for Economic Cooperation and Development (OECD), eco-innovation reflects the development of newly improved processes and products that generate environmentally-friendly outcomes. Eco-innovation has been paid attention because it is a key factor in overcoming resource constraints and environmental problems. As eco-innovation induces positive environmental effects (Faucheux and Nicolaï, 2011, Costantini et al., 2017; Hashmi and Alam, 2019), many governments have been interested in improving green technologies in the private and public sectors. For instance, they encouraged to develop environmental patents and spent R&D expenditures for environmentally-friendly technologies. Accordingly, the OECD reported that patent applications and governmental expenditures increased dramatically across countries. While the number of environmental patents increased from about 21,152 to 81,129 between 2000 and 2018, the environmental R&D expenditures rose from about 156 to 199 million dollars over the same period. The patent applications and governmental expenditures were considered to enhance the quality of innovation and induce the improved environmental performance (Acemoglu et al., 2014; Carrión-Flores and Innes, 2010).

Along with the growing interests in eco-innovation, many empirical studies identified the demand- and supply-side factors that drive eco-innovation. For instance, as a demand-side factor, Kesidou and Demirel (2012) showed that the public demand for corporate social responsibility would form social pressures on demanding more environmentally-friendly products, leading to a commitment of firms to financing on green issues. In addition, due to growing demand for environmentally-friendly products, it appeared that eco-innovative firms were more profitable than other firms (Wagner, 2007; Horbach, 2008; Doran and Ryan, 2012). On the other hand, as a supply-side factor, the importance of firms' organizational capabilities was emphasized because firms with a high level of organizational capabilities tended to establish eco-innovative production processes pursuing source reduction, pollution prevention, and green product design (Kesidou and Demirel, 2012). Beyond the demand- and supply-side factors, recent studies also found out that information disclosure and media attention facilitated green innovation (He et al., 2022; Kong et al., 2022; Tan et al., 2022)

Moreover, many studies showed that environmental regulation and policy were effective in enhancing the type and quality of eco-innovation (Demirel and Kesidou, 2011; Wagner and Llerena, 2011; Horbach et al., 2012; Triguero et al., 2013; Kesidou and Wu, 2020). According to Kesidou and Wu (2020) who examined the contribution of environmental regulations to green patents in China, they showed that environmental regulations in emerging and developed economies induced a higher volume and intensity of green patents. Moreover, as a stimulator of eco-innovation, preemptive regulatory activities were considered to help firms take the first-mover advantage in the international markets because firms could increase competitiveness in environmental performance while conforming to internationally agreed standards for environment (Horbach et al., 2012).

While there are many factors that stimulate eco-innovation, many studies also showed how eco-innovation was associated with environment and economy. Costantini et al. (2017) showed eco-innovation would have positive impact on environment because firm’s eco-innovative behavior could reduce negative externalities of production by shaping sustainable supply chains. Hashmi and Alam (2019) found evidence that environmentally-friendly patents mitigated environmental degradation across OECD countries. In addition, regarding the economic performance of eco-innovation, eco-innovation was considered to create green jobs, contributing to economic growth (Cheng et al., 2014; Cecere and Mazzanti, 2017).

Despite many studies regarding eco-innovation, the literature has paid little attention to the relationship of eco-innovation with export performance due to the limited availability of data. However, as the OECD recently published the dataset for eco-innovation, this study attempts to evaluate how eco-innovation contributes to the exports of environmentally-friendly products. Based on trade theory that deals with the linkages of traditional innovation with exports (Krugman, 1979; Grossman and Helpman, 1991; Eaton and Kortum, 2011), the specific objectives of this study are as follows. First, this study explores the dynamics of environmentally-friendly exports to understand the short-run and long-run adjustment in the exports. Second, this study determines whether private eco-innovation contributes to the exports of environment-related products with a focus on the environmental patents of firms. Third, this study examines how public eco-innovation affects the exports of environment-related products by testing for the effectiveness of the environment-related R&D expenditures.

II. Data

A panel dataset is constructed to cover 22 countries for the 2000-2018 period as described in Table 1; the detailed information about the selected countries are provided in Appendix 1. The major OECD countries are selected for the empirical analyses because they have distinguished features for the linkage between eco-innovation and environmentally-friendly products. First, the selected OECD countries are all classified as high-income countries that maintain similar standards and regulations for the mitigation of carbon emissions, showing significant development of eco-innovation (Puertas and Marti, 2021). Second, the governments of major OECD economies and the International Energy Agency (IEA) have agreed to expand the public-sector's investments in low carbon and clean energy research and development (R&D) (Al Mamun et al., 2018; Paramati et al., 2021). They have put great importance to environmentally-friendly products and required the capabilities of improving physical infrastructure and institutional quality (Can et al., 2021). Third, considering that major OECD countries are leading the development of eco-innovation and related industry, the investigation of the selected OECD countries can provide helpful guidance for other developing economies to design better green policies for eco-innovation. (Paramati et al., 2021; Mahmood et al., 2022).

〈Table 1〉 Data Description

Contents			Mean	Std.Dev.	Min	Max
Bilateral export		ton	85,955	236,818	2.323	3,038,643
		price ($/ton)	22,010	33,039	14.049	1,900,435
	Bilateral export of products related to pollution management	ton	34,244	93,153	0.478	1,290,749
		price ($/ton)	21,373	21,397	31.705	443,409
	Bilateral export of products related to cleaner technologies	ton	8,781	37,496	0.002	913,698
		price ($/ton)	19,552	41,597	29.360	1,900,435
	Bilateral export of resource management	ton	38,904	118,488	0.196	1,623,764
		price ($/ton)	16,933	19,982	90.300	515,001
Patents applications related to environment (Numbers)			797.98	1,467.94	1.00	7,794.27
Government R&D expenditures related to environment (Constant 2015, million $)			240.35	274.99	0.643	1,505.28
Gross domestic product per capita (Constant 2015 $)			38,170.19	14,777.58	8,914.59	75,953.58
Environmental Policy Stringency Index (Scale 0-6)			2.699	0.805	0.527	4.555

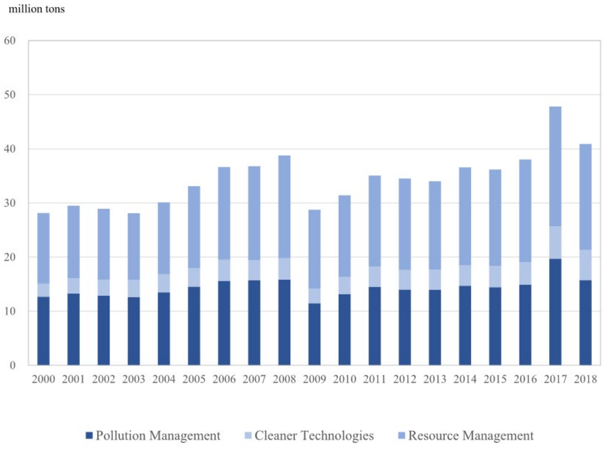
Source: OECE Stat, UN Comtrade, and World Bank.

1. Exports of Environment-Related Products

The data for the exports of environment-related products are collected mainly from the OECD Statistics and the United Nations Comtrade (Figure 1). In this study environment-related products include “goods and services to measure, prevent, limit, minimize, or correct environmental damage to water, air, and soil, as well as problems related to waste, noise and eco-systems (Steenblik, 2005).” In addition, according to OECD, the exports of environment-related products are categorized into the exports of products related to pollution management, cleaner technologies, and resource management.

The products for pollution management include air pollution control, wastewater management, solid waste management, remediation and clean-up, noise and vibration abatement, environmental monitoring, analysis, and assessment, while the cleaner technologies and products include cleaner/resource efficient technologies and processes, and cleaner/resource efficient products. The products for resource management include indoor air pollution, water supply, recycled materials, renewable energy plant, heat/energy savings and management, sustainable agriculture and fisheries, sustainable forestry, natural risk management, eco-tourism, etc.

〈Figure 1〉 Exports of Environmentally-Friendly Products



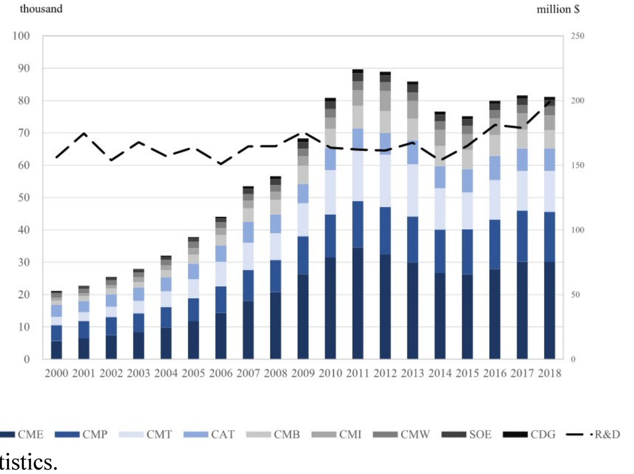
Source: OECD Statistics and United Nations Comtrade.
Note: The exports are measured in million tons.

In Figure 1, it appeared that environmentally-friendly products increased over the period except for 2007-08 financial crisis, The total exports increased gradually from about 30 million tons in 2000 to 43 million tons in 2018. Specifically, the exports of pollution and resource management products accounted for about 43% and 44% of the total exports in 2000, respectively, but they changed to about 37% and 46% in 2018. The exports of pollution management products decreased slightly, but the exports of cleaner technologies and products increased from about 8% in 2000 to about 13% in 2018. While the exports of products for resource management were the highest over the period, the exports for renewable energy plant accounted for about 45% every year, which was the highest in the exports of resource management products.

2. Eco-Innovation

Regarding eco-innovation, we use the number of patent applications to environment and the government R&D expenditures for environment to proxy private and public eco-innovations. The data for environmental patents are considered to represent the innovative and technological activities of firms for environment (Zvi, 1990; Nagaoka et al., 2010; Choi and Han, 2018). Specific information about environmental patents is provided in Appendix 2. In addition, the data for environment-related R&D expenditures reflect the public efforts on developing environmentally-friendly technologies and products (Arimura et al., 2007; Wiesenthal et al., 2012). Most R&D expenditures focus on the activities developing environmental technologies against climate change and resource depletion.

〈Figure 2〉 Number of Patents and R&D Expenditures



Source: OECD Statistics.
Note: The number of patents is measured in thousand, and the R&D expenditures are measured in million dollars. Detailed information about patents is provided in Appendix 2.

In Figure 2, it appeared that the total number of patent applications increased from about 21,152 in 2000 to 81,129 in 2018, reaching the highest number of 88,906 in 2012. In 2018 alone, the majority of patents resulted from ‘climate change mitigation technologies related to energy generation, transmission or distribution’ (CME, 37.0%), ‘climate change mitigation technologies in the production or processing of goods’ (CMP, 19.2%), ‘climate change mitigation technologies related to transportation’ (CMT, 15.6%), and ‘climate change adaptation technologies’ (CAT, 8.4%). On the other hand, the total environmental R&D expenditures grew steadily from about 156 million dollars in 2000 to 199 million dollars in 2018. Specifically, Germany spent, on average, about 921 million dollars for environmental R&D between 2000 and 2018, which was the largest investment in eco-innovation among the selected countries. The United States followed with the value of about 646 million dollars, and Japan ranked the 3rd with the value of about 636 million dollars.

Ⅲ. Methodology

This study uses the dynamic panel model to explore the dynamics of environmentally-friendly exports and examine the effects of eco-innovation on the exports in quantity. Using the dynamic panel model allows to understand the dynamic adjustment in the exports and quantify the short-run and long-run effects of eco-innovation on the exports of environmentally-friendly products. While the estimates represent the short-run effects directly, we estimate the long-run effects combining with the estimate of dynamic adjustment term (Carstensen and Toubal, 2004).

Starting with the static panel model yields

$$y_{ij,t} = \alpha + \beta x'_{ij,t} + \mu_i + \delta_t + \epsilon_{ij,t} \tag{1}$$

where i and t denote country and year, respectively. In Equation (1), $y_{ij,t}$ indicates the exports from country i to country j, $x_{ij,t}$ explanatory variables including eco-innovation, μ_i unobservable country-specific term, δ_t time-specific term, and $\epsilon_{ij,t}$ the error term. In addition, α and β are the parameters to be estimated. To construct the dynamic panel model, the lagged dependent variable is incorporated into the static panel model since the past exports affect the current exports (Egger, 2001; Montobbio, 2003). The dynamic panel model is written

$$y_{ij,t} = \alpha + \theta y_{ij,t-1} + \beta x'_{ij,t} + \mu_i + \delta_t + \epsilon_{ij,t} \tag{2}$$

where θ represents the dynamic adjustment in the exports. In Equation (2), the estimation of the model with the lagged dependent variable produces the endogeneity problem. A way of solving the endogeneity problem is to take the difference in Equation (2) and apply the generalized method of moments (GMM) (Arellano and Bond, 1991), but our estimation applies the system GMM proposed by Blundell and Bond (1998) to use the instruments that reflect all moment conditions. The system GMM is known to produce more consistent and efficient estimates than the difference GMM (Hayakawa, 2007).

To obtain the long-run estimates (γ), we follow the computational approach suggested by the previous studies (Papke and Wooldridge, 2005; Kripfganz, 2016; Canh et al., 2019; Heo et al., 2020; Immurana et al., 2021; Ryu et al., 2021). That is, the short-run effects are represented directly by the estimates (β) of the dynamic panel model, but the long-run effects are calculated by combining the estimates of explanatory variables with the estimate of dynamic adjustment term. The long-run effects are calculated by

$$\gamma = \frac{\beta}{1-\theta} \tag{3}$$

which are greater than the short-run effects because θ ranges from zero to unity.

To model the exports of environmentally-friendly products appropriately, we include the variables for eco-innovation in the relative term to represent how much an exporting country achieves eco-innovation relative to an importing country. For private eco-innovation, we divide the number of patent applications (PAT) of a domestic country by that of a partner country. The same definition is applied to public eco-innovation represented by environmental R&D expenditures (RND).

The specific dynamic panel model is written

$$y_{ij,t} = \theta y_{ij,t-1} + \beta_1 P_{ij,t} + \beta_2\left(\frac{PAT_{i,t}}{PAT_{j,t}}\right) + \beta_3\left(\frac{RND_{i,t}}{RND_{j,t}}\right) + \beta_4 GDP_{j,t} + \beta_5 REG_{i,t} + \mu_i + \delta_t + \epsilon_{ij,t} \tag{4}$$

where y represents the quantities of environmentally-friendly products exported. In Equation (4), we include additional explanatory variables such as the domestic export price (P), real gross domestic product per capita (GDP) of an importing country, and environmental policy stringency index of an exporting country (REG). While the export price indicates the price competitiveness, the GDP indicates the purchasing power of an importing country. In addition, the regulatory environment in a country is represented by the environmental policy stringency index that ranges from 0 (not stringent) to 6 (most stringent).

Ⅳ. Results

Tables 2 shows the estimation results of our dynamic panel model specified in Equation (4). While the results are reported for the total environment-related exports, the exports for pollution management, cleaner technologies and products, and resource management, the results of Arellano-Bond and Hansen J tests indicate that the model fits to the data well. That is, the test results show that there are no second-order serial correlation and over-identification problems. While the fixed effect (FE) estimates are reported for the static panel model, our interpretations are based on the system-GMM estimates for the dynamic panel model because the FE estimates are inconsistent in the dynamic panel model (Nickell, 1981; Canh et al., 2019; Leszczensky and Wolbring, 2022).

In Table 2, the estimates of the lagged dependent variable range from 0.96 to 0.98, showing that there exists the dynamic adjustment to the long-run equilibrium. The results show that the adjustment is very sluggish to recover the long-run equilibrium. Regarding private eco-innovation, the effects on the exports vary with the properties of the environmental products. The relative patent applications have no effects on the

〈Table 2〉 Estimation Results

	Total		Pollution Management		Cleaner Technologies and Products		Resource Management	
	FE	System GMM	FE	System GMM	FE	System GMM	FE	System GMM
y_{it-1}		0.983*** (0.008)		0.959*** (0.016)		0.979*** (0.013)		0.967*** (0.016)
P_{ijt}	−0.555*** (0.126)	−0.404*** (0.097)	−0.099*** (0.026)	−0.118*** (0.037)	−0.007* (0.004)	−0.013 (0.016)	−0.134*** (0.048)	−0.456*** (0.113)
$\frac{PAT_{it}}{PAT_{jt}}$	6.108** (2.916)	0.507 (0.536)	−1.116 (0.943)	0.145 (0.395)	1.532 (1.136)	0.191 (0.192)	5.365** (2.234)	0.798* (0.442)
$\frac{R\&D_{it}}{R\&D_{jt}}$	3.265 (9.558)	9.427*** (3.016)	3.430 (3.243)	4.711* (2.416)	7.183 (5.828)	1.639*** (0.558)	−4.536 (6.089)	6.382*** (2.000)
GDP_{jt}	2.426*** (0.515)	0.108** (0.046)	0.571*** (0.156)	0.034 (0.037)	0.317*** (0.114)	0.003 (0.011)	1.351*** (0.360)	0.110*** (0.038)
REG_{it}	−394.2 (2,925.7)	−739.5 (1,064.3)	1,077.3 (901.1)	452.7 (663.8)	70.85 (243.2)	−339.4 (328.5)	−1,800.1 (2,251.2)	−1,061.1 (812.0)
Hansen J (p-value)		0.333		0.321		0.819		0.325
AR(1) (p-value)		0.000		0.001		0.014		0.002
AR(2) (p-value)		0.236		0.805		0.255		0.435

Note: Robust standard errors are in parenthesis; *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively; The Hansen J tests are for the over-identified restrictions on the GMM estimators, asymptotically; AR(1) and AR(2) are the tests for first-order and second-order serial correlation, asymptotically N(0,1).

exports except for resource management. There exists statistical evidence that the increased number of environmental patent applications induces an increase in the exports of products related to resource management (5.37). The results are attributed to the patent applications that consist of climate change mitigation technologies for renewable energy, resource management, and sustainable industrial development.

However, unlike the effects of private eco-innovation, the results reveal that public eco-innovation enhances all the exports. While they contribute to the total exports of environmentally-friendly products (9.43), the increased R&D expenditures contribute to the exports for pollution management (4.71), cleaner technologies and products (1.64), and resource management (6.38). Among the exports of environment-related products, it appears that the environmental R&D expenditures are more effective in enhancing the exports of products for resource management. As the relative number of patents contributes to the exports of products for resource management, public eco-innovation has also positive effects on the exports of products for resource management. Moreover, the results show that the contribution of the environmental R&D expenditures is much greater than that of the environmental patent applications. The results imply that the exports of environment-related products are induced mainly by the governments' expenditures for overcoming climate change and resource depletion.

Additionally, the estimates of the domestic export price for most types of exports are negative and range from −0.12 to −0.46, showing that the increased domestic export price reduces the exports (Athanasoglou and Bardaka, 2010). While the export price affects the total exports, it does not appear that the export price affects the exports of cleaner technologies and products. Regarding the purchasing power of an importing country, the results show that higher per-capita GDP is associated only with an increase in the exports of products for resource management. Since the exports of products for resource management account for the largest portion of the total exports, it seems that higher purchasing power of an importing country results in more purchases of products for resource management. Regarding the regulatory environment, the estimates for the environmental policy stringency index are not statistically significant for all types of exports.

Tables 3 reports the short-run and long-run effects of eco-innovation on the exports. All the long-run effects in absolute terms are greater than the short-run effects since the estimates of lagged dependent variables range from zero to unity. In Table 3, with a focus on eco-innovation effects, the long-run effects of the relative number of patents on the exports are valid only for the exports of products for resource management (24.00). The results are similar to the short-run effects, but the extent to which private eco-innovation affects the exports is much greater for the long-run effects due to the dynamic adjustment.

Moreover, the results show that the long-run effects of environmental R&D expenditures become greater than the short-run effects. The effects are 569.7 for the total exports, 115.6 for pollution management, 78.61 for cleaner technologies and products, and 191.8 for resource management, respectively. The results indicate that the R&D expenditures are the most effective in enhancing the exports of products for resource management. Compared with the estimates for the short-run effects, it appears that

〈Table 3〉 Dynamic Effects of Eco-innovation on Exports

	Total		Pollution Management		Cleaner Technologies and Products		Resource Management	
	Short-run Effect	Long-run Effect	Short-run Effect	Long-run Effect	Short-run Effect	Long-run Effect	Short-run Effect	Long-run Effect
P_{ijt}	−0.404*** (0.097)	−24.45** (11.90)	−0.118*** (0.037)	−2.895* (1.628)	−0.013 (0.016)	−0.625 (1.129)	−0.456*** (0.113)	−13.71** (6.374)
$\frac{PAT_{it}}{PAT_{jt}}$	0.507 (0.536)	30.65 (35.19)	0.145 (0.395)	3.563 (10.39)	0.191 (0.192)	9.175 (9.201)	0.798* (0.442)	24.00* (14.28)
$\frac{R\&D_{it}}{R\&D_{jt}}$	9.427*** (3.016)	569.7* (305.7)	4.711* (2.416)	115.6*** (33.14)	1.639*** (0.558)	78.61* (45.09)	6.382*** (2.000)	191.8* (116.1)
GDP_{jt}	0.108** (0.046)	6.543 (4.074)	0.034 (0.037)	0.831 (1.155)	0.003 (0.011)	0.154 (0.432)	0.110*** (0.038)	3.309* (1.715)
REG_{it}	−739.5 (1,064.3)	−44,692.4 (69,858.0)	452.7 (663.8)	11,104.6 (13,951.2)	−339.4 (328.5)	−16,277.7 (11,140.5)	−1,061.1 (812.0)	−31,889.3 (23,383.0)

Note: Robust standard errors are in parenthesis; *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

private and public eco-innovations can contribute to the exports even in the long run. In particular, as the long-run effects of R&D expenditures increase dramatically, it is expected that public eco-innovation will be a main factor enhancing the exports in the future.

In effect, the findings indicate that both private and public eco-innovations contribute to the exports of environmentally-friendly products, and the effects are more obvious when it comes to the long run. Considering the positive long-run effects of eco-innovation on the exports, our results support that eco-innovation can play a substantial role in expanding environment-related products industry. The long-run effects of R&D expenditures related to environment, especially, are remarkable, implying that eco-innovation driven by public finance is important for enhancing the exports. As private eco-innovation has potential for improving the exports though, an incentive mechanism can encourage firms to facilitate their eco-innovative activities. Along with the public sector's eco-innovation, if firms' eco-innovative behavior creates eco-friendly goods and services and builds a new production process meeting the environmental standards, the exports of environment-related products may grow further, thereby addressing externalities involved in its production and contributing to environment.

Ⅴ. Conclusions

As eco-innovation is a key factor driving future economic growth coping with environment, it has been of interest to develop environmentally-friendly technologies and products in both private and public sectors. Moreover, it is considered that private and public eco-innovations have contributed to expanding the markets of environment-related products, and their diffusion across industries and countries has stimulated the trade meeting the environmental standards. To understand the role of eco-innovation in exports, this study first attempts to examine the dynamic effects of eco-innovation on the exports of environmentally-friendly products with a focus on major OECD countries.

Employing the dynamic panel model, this study contributes to the literature by exploring the dynamics of the exports and examining the short-run and long-run effects of eco-innovation on the exports of environmentally-friendly products.

The results reveal that, with the persistence of the exports, the adjustment in the exports exists to recover the long-run equilibrium. In addition, the results show that private and public eco-innovations are beneficial for enhancing the environmentally-friendly exports. While the results find that patent applications to environment are associated only with an increase in the exports of products for resource management, environmental R&D expenditures contribute to all types of the exports. Moreover, the results reveal that the long-run effects of eco-innovation on the exports are greater than the short-run effects. From the short-run and long-run estimates, the results support that public eco-innovation is more effective in improving future export performance than private eco-innovation.

The findings provide some policy implications. First, the government needs to keep investing in R&D activities for developing eco-technologies and products against climate change and resource depletion. The government-driven eco-innovation will continue to increase the exports and expand the environment-related industries, which ultimately will contribute to satisfying international standards for environment and achieving sustainable development coping with environmental, economic and social norms. Second, due to the limited contribution of private eco-innovation to the exports, it is necessary for the government to encourage and incentivize firms to develop voluntarily their own eco-friendly technologies and diffuse them to other firms' production processes. If creating business environment for firms' innovative activities is linked to an increase in the exports of environment-related products, it can contribute to mitigating the externality problems and generating substantial profits from the exports, thereby improving competitiveness in the international market.

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[Appendix]

〈Appendix Table 1〉 Data Description for Selected Countries

Country	GDP per capita		Patent		R&D (in million USD)		Exports (ton)		Regulation Index (0 – 6)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Australia	52,739.4	3,953.9	232.7	28.6	157.4	37.4	1,103	2,686	2.3	0.8
Austria	42,846.2	2,198.5	167.0	60.1	42.0	16.8	18,738	50,714	2.6	0.5
Canada	40,402.9	3,444.1	367.4	63.4	330.6	31.8	28,774	157,454	2.5	0.9
Czech	16,036.9	2,062.5	21.1	8.7	46.1	3.9	28,296	80,682	2.6	0.5
Denmark	52,138.9	2,074.9	213.6	84.6	43.6	9.8	13,673	37,369	3.3	0.8
Finland	42,846.4	2,367.0	172.8	59.8	38.6	7.3	5,210	13,246	3.2	0.6
France	35,794.7	1,223.3	887.3	338.7	469.9	149.5	25,362	52,597	3.3	0.9
Germany	38,186.9	2,839.7	2,345.6	653.7	900.4	80.2	96,428	174,261	2.9	0.4
Ireland	50,895.1	8,441.8	29.1	11.9	10.8	6.2	3,168	19,873	2.3	0.5
Italy	32,109.1	1,231.5	309.8	106.0	379.6	80.2	45,088	95,513	3.1	0.8
Japan	33,409.3	1,444.2	4,360.0	2,136.0	567.9	415.0	17,842	45,180	3.3	0.5
Korea	24,285.3	4,246.6	1,185.1	778.4	436.2	107.7	14,239	45,365	2.7	0.8
Netherlands	43,875.2	2,122.7	320.3	98.7	70.0	53.0	20,774	63,149	2.8	0.7
Norway	72,716.8	2,448.4	100.0	27.1	57.3	16.1	2,597	7,618	3.0	0.8
Portugal	19,390.0	620.2	17.9	10.1	35.6	17.9	9,921	31,230	2.3	0.5
Slovakia	13,609.1	2,699.0	7.0	3.6	11.8	4.9	9,107	22,890	2.2	0.6
Slovenia	20,076.1	1,913.7	9.1	6.1	9.6	4.3	9,102	39,929	2.1	1.0
Spain	25,770.4	1,049.9	198.3	90.6	399.3	149.6	21,903	53,446	2.3	0.4
Sweden	47,659.5	3,567.5	319.2	116.7	55.1	14.5	13,326	36,346	3.3	0.4
United Kingdom	43,334.1	2,132.1	648.2	170.7	336.5	66.8	24,010	83,210	2.7	0.8
United States	53,564.0	3,044.7	4,846.9	1,247.5	649.6	106.9	43,168	152,556	2.0	0.6

〈Appendix Table 2〉 Patent Classification

	Description
CME	Climate change mitigation technologies related to energy generation, transmission or distribution
CMP	Climate change mitigation technologies in the production or processing of goods
CMT	Climate change mitigation technologies related to transportation
CAT	Climate change adaptation technologies
CMB	Climate change mitigation technologies related to buildings
CMI	Climate change mitigation in information and communication technologies (ICT)
CMW	Climate change mitigation technologies related to wastewater treatment or waste management
SOE	Sustainable ocean economy
CDG	Capture, storage, sequestration or disposal of greenhouse gases