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Knowledge Spillover Effects on Agglomerations of Environment-related Industries†

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Abstract : The number of environment-related technologies has increased remarkably over the past two decades, as has the public's interest in effective resource use and ways to reduce the effects of global warming. Industries that are based on environment-related technologies are thus growing rapidly. Previous studies revealed that externalities derived from the population concentration in urban areas positively affect agglomerations of high-tech industries. Such externalities have been named the "knowledge spillover effect." The purposes of the present paper are to (1) give a thumbnail sketch of the locations of environment-related industries around the world, using the Organisation for Economic Co-operation and Development environment-related patent statistics, and (2) explicate the effects of the Marshall-Arrow-Romer (MAR) and Jacobs externalities, which result from population concentrations in urban areas, on the agglomeration of environment-related industries in Sweden. The analysis revealed that environment-related industries are located chiefly in urban areas across the globe, and that only the MAR externalities influenced positively on the agglomeration of these industries in Sweden.

Keywords: innovation, environment-related industry, externalities, knowledge spillover effects, OECD patent statistics

1. INTRODUCTION

Most developed countries transformed from an industrial society, which is based on labor or capital, to a knowledge society, in which knowledge and technology are emphasized. For such a societal change to take place, innovation is essential to build new companies and to maintain the competitiveness of these companies, and in turn, to grow new industries and achieve national competitiveness in a country. In recent years, new knowledge and technologies that enhance innovation have received a great deal of societal and academic interest (Malmberg and Maskell 1997; Porter 1998; Cooke et al. 2011; Asheim and Parrilli 2012). The growing interest in environment-related industries based on environmental technologies is an example of this attention. Since the collapse of the information technology (IT) bubble in the first half of the 2000s, many institutional investors have changed their investment focus from IT companies to environment-related industries. The start of the first commitment period of the Kyoto Protocol in 2008 also enhanced investment in environment-related industries. In line with the surging social interest in ways to protect the natural environment, such as effective resource use and the prevention of global warming, environmental technologies designed to reduce environmental loads have developed rapidly in recent years, and in turn, environment-related industries have been growing markedly.

Under such circumstances, several metrics were developed to grasp the status of knowledge associated with various innovations and related environmental technologies. The

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OECD patent statistics and the new national economic system, which was adopted by the United Nations in 2008, are the examples, and they also became the global standards[1]. According to OECD (2008), the number of environment-related patents almost doubled from 1998 to 2008, indicating an increase in the number of environmental technologies and environment-related industries based on these technologies[2]. Other than the OECD (2008) report, which mentioned only limited categories of environmental technologies, there are only a limited number of studies providing an overview of the global development of the environmental industries.

In addition to the global development of environment industries, there is another research topic left behind concerning these industries. This topic is associated with drivers causing agglomeration of the environment related industries. Although this topic did not attract much attention and was left behind, studies on industrial agglomeration of these industries were chiefly conducted from the viewpoints of competitiveness or productivity, and relationships between it and green innovation. Once a green innovation is introduced, it may bring the birth of a new environmental company. In such a case, environment-related companies accumulate in a city/region and yield a large amount of green products and/or services. As a result, the city/region has a high rate of economic growth and productivity. At the same time, this city/region acquires high competitiveness. In this context, some research focused on relationship between green innovation and growth/competitiveness (Tessitore et al. 2010; Daddi et al. 2012). In a series of their study, Tessitore et al. (2013) revealed a positive connection between the green innovation and growth/competitiveness.

Albeit Tessitore and his colleagues identified such relationship, they did not mention the drives of the green innovations. A very few scholars mentioned such drives. Carrillo-Hermosilla et al. (2010) pointed out the diversity of innovations and their interactions lead to production of a new green innovation, while Horbach (2014) stressed that highly qualified workers are necessary for the creation of green innovations. Regarding such drivers, Yamashita (2013) mentioned the spillover effects of skilled workers on agglomerations of these industries.

In cities all over the world, the scale economies could be affected by the agglomeration of environmental industries. Yamashita (2013) found that environmental industries were concentrated in large urban areas on a global scale. Using the number of environment-related patents as an indicator of innovation, the results of that study indicated that the externalities of high population density can influence the agglomeration of high-tech industries. In other words, because companies and professionals are accumulated at high density in small spatial areas within cities, innovative knowledge, skills and technologies are shared among these companies and professionals, and as a result, the creation and growth of high-tech industries can be encouraged in urban environments. This type of externalities is referred to as a knowledge spillover effect (Jaffe et al. 1993).

Externalities that enhance industry agglomerations can be classified into two domains (Beaudry and Schiffauerova 2009). One domain is the so-called Marshall-Arrow-Romer (MAR) externalities, and the other is the Jacobs externalities. In the MAR domain, it is assumed that a regional specialization of an industry or a specialization in industry agglomeration can promote regional economic growth. In the Jacobs domain, it is thought that rather than specialization, diversity in industries can enhance economic growth and technological innovation. Another type of externalities, the Porter externalities, is similar to the MAR externalities. In both, the regional specialization of industries or a specialization in industry agglomeration is thought to lead to the regional economic growth. However, MAR and Porter externalities are different in the following way. In the MAR domain, it is emphasized that an exclusive environment of a monopolized company or industry could result in the industrial accumulation and the regional economic growth. In the Porter externalities, in contrast, it is stressed that a competitive environment with a group of companies or industries can bring innovation or economic growth.

Based on their analysis of peer-reviewed papers, Beaudry and Schiffauerova (2009) concluded that both MAR and Jacobs externalities have positively affected industry agglomeration and economic growth, and they summarized the characteristics of these two types of externalities as follows: (1) the MAR externalities were dominant in the analyses of industries categorized in the broad industrial classification, whereas the Jacobs externalities affected the articulated classification. Both

[1] The United Nations Statistics Division relinquished the version of the System of National Account (93SNA) as it adopted a new version (08SNA). The 08SNA includes innovation, which creates knowledge.

[2] According to the OECD patent statistics, the number of environment-related patents increased from 71,680 to 148,974 during the aforementioned period.

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influenced the medium classification. (2) Regarding the combinations of industry classification and geographic units, neither the MAR nor the Jacobs externalities had an influence in analyses using the broad industry classification and disaggregated spatial units or when using the coarse industry classification and aggregated spatial units. Both externalities have effects in both industries classification and spatial units in between. (3) Regarding the traditional and high-tech industries, the MAR externalities are somewhat more influential in traditional industries compared to the Jacobs externalities, whereas the Jacobs externalities have a greater impact on high-tech industries. Both externalities affect the intermediate industries between traditional and high-tech industries. (4) Concerning the life stage of industries, the Jacobs externalities are dominant at the early stage, whereas the MAR externalities have a greater effect at the final stage.

Neffke et al. (2012) confirmed these findings in their study of 12 Swedish manufacturers. They found that when researchers used innovation—which was represented by factors such as the total amount of research and development costs and the number of patents as the dependent variable instead of economic growth—the Jacobs externalities had greater influence than the MAR externalities in analyses using an articulated or less coarse industry classification, whereas the MAR externalities were more dominant in analyses using the broad industry classification.

Beaudry and Schiffauerova (2009) also summarized the effects of both externalities by country. On the basis of just one case, they reported that only the MAR externalities had a positive effect in Sweden. For Japan, using four cases, they indicated that only the MAR externalities were effective in one case, and that only the Jacobs externalities were effective in another case. Both types of externalities affected the other two cases. However, it remains difficult to conclude which externalities are dominant in Sweden and Japan, and further research on the effects of the MAR and Jacobs externalities on industry agglomeration in both countries is needed.

Moreover, regarding the effects of these two types of externalities on high-tech industries, studies of high-tech industries have focused mainly on the information and communications technology (ICT) and biotechnology, and thus the accumulation of analyses using an environment-related industry or innovation as the dependent variable is not sufficient. Taking the aforementioned research circumstances into consideration and using the OECD environment patent data, I conducted the present study to provide an overview of regional locations of environment-related industries across the globe and to identify the effects of the MAR and Jacobs externalities—which resulted from population accumulations in urban areas—on the agglomeration of environment-related industries. Section 2 describes the research methods for revealing the regional locations of environment-related industries across the world and effects of the two externalities. After the regional locations of environment-related industries are presented in Section 3, I examine the effects of the externalities in Section 4. The final section is a summary of both the regional locations of and the characteristics of the externality impacts on the environment-related industries, along with suggestions for further study directions.

2. METHODS

As mentioned above, environment-related industries are the focus of the present study. Using the number of environment-related patents aggregated by region, I examined the accumulation of environment-related industries. As Oltra et al. (2009) pointed out, these patents are good indicators for measuring environment-related innovations. I used the OECD patent statistics to gather the environment-related patents[3].

These statistics are aggregated by Territorial Level 3 (TL3), which is the OECD's unique regional statistic unit. I summed the total number of OECD patent statistic data issued between 1998 and 2008, and used the summed figures to examine the locations of the environment-related industries worldwide. To reveal effects of the MAR and Jacobs externalities, I also used the OECD's TL3 regions. These regions are equivalent to counties in Sweden or to the states in the U.S. There are 21 counties, i.e. TL3 regions, in Sweden.

Using six of the seven categories of OECD environment technology patent statistics, I examined regional agglomerations of the environment-related industries and the effects of the MAR and Jacobs externalities <Table 1>. Category E was excluded because of its lack of data. The seven categories are

[3] The data were obtained from the following web site: http://www.oecd.org/sti/innovationinsciencetechnologyandindustry/oecdpatentdatabases.htm accessed 15 Feb 2013

Table 1. Classifications of environment-related patents by OECD

A. GENERAL ENVIRONMENTAL MANAGEMENT	1. Air pollution abatement (from stationary sources)	
	2. Water pollution abatement	
	3. Waste management	i. Solid waste collection
		ii. Material recycling
		iii. Fertilizers from waste
		iv. Incineration and energy recovery
		v. Landfilling [n.a.]
		vi. Not elsewhere classified
	4. Soil remediation	
	5. Environmental monitoring	
B. ENERGY GENERATION FROM RENEWABLE AND NON-FOSSIL SOURCES	1. Renewable energy generation	i. Wind energy
		ii. Solar thermal energy
		iii. Solar photovoltaic (PV) energy
		iv. Solar thermal-PV hybrids
		v. Geothermal energy
		vi. Marine energy (excluding tidal)
		vii. Hydro energy - tidal, stream or damless
		viii. Hydro energy - conventional
	2. Energy generation from fuels of non-fossil origin	i. Biofuels
		ii. Fuel from waste (e.g. methane)
C. COMBUSTION TECH NOLOGIES WITH MITIGATION POTENTIAL (e.g. using fossil fuels, biomass, waste, etc.)	1. Technologies for improved output efficiency (Combined combustion)	i. Heat utilization in combustion or incineration of waste
		ii. Combined heat and power (CHP)
		iii. Combined cycles (incl. CCPP, CCGT, IGCC, IGCC+CCS)
	2. Technologies for improved input efficiency (Efficient combustion or heat usage)	
D. TECHNOLOGIES SPECIFIC TO CLIMATE CHANGE MITIGATION	1. Capture, storage, sequestration or disposal of greenhouse gases	i. CO2 capture and storage (CCS)
		ii. Capture or disposal of greenhouse gases other than carbon dioxide (N2O, CH4, PFC, HFC, SF6)
E. TECHNOLOGIES WITH POTENTIAL OR INDIRECT CONTRIBUTION TO EMISSIONS MITIGATION	1. Energy storage	
	2. Hydrogen production (from non-carbon sources), distribution, and storage	
	3. Fuel cells	
F. EMISSIONS ABATEMENT AND FUEL EFFICIENCY IN TRANSPORTATION	1. Technologies specific to propulsion using internal combustion engine (ICE) (e.g. conventional petrol/diesel vehicle, hybrid vehicle with ICE)	i. Integrated emissions control (NOX, CO, HC, PM)
		ii. Post-combustion emissions control (NOX, CO, HC, PM)
	2. Technologies specific to propulsion using electric motor (e.g. electric vehicle, hybrid vehicle)	
	3. Technologies specific to hybrid propulsion (e.g. hybrid vehicle propelled by electric motor and internal combustion engine)	
	4. Fuel efficiency-improving vehicle design (e.g. streamlining)	
G. ENERGY EFFICIENCY IN BUILDINGS AND LIGHTING	1. Insulation (incl. thermal insulation, double-glazing)	
	2. Heating (incl. water and space heating; air-conditioning)	
	3. Lighting (incl. CFL, LED)	

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as follows. (1) Category A (General Environment Management) includes technologies of soil pollution control and sewage and waste-related treatments. (2) Category B (Energy Generation from Renewable and Non-Fossil Sources) consists of technologies for energy production associated with wind, solar, geothermal and other energy sources. (3) Category C (Combustion Technologies with Mitigation Potential) contains technologies related to cogeneration such as waste power generation. (4) Category D (Technologies Specific to Climate Change Mitigation) includes mainly technologies of carbon dioxide capture and storage (CCS) and other technologies concerning the capture and storage of different greenhouse gases. (5) Category E (Technologies with Potential or Indirect Contribution to Emissions Mitigation) comprises technologies related to fuel cells and the production, transportation and storage of hydrogen. (6) Category F (Emission Abatement and Fuel Efficiency in Transportation) encompasses the transport-related technologies including exhaust gas regulation systems and hybrid engines. (7) Category G (Energy Efficiency in Building and Lighting) is the technologies associated with the energy efficiency of heating and lighting in buildings.

Using the multiple regression model, I identified the effects of the MAR and Jacobs externalities on agglomerations of the environment-related industries for each of the six categories (A, B, C, D, F, G). The dependent variables were the number of environment-related patents in the six categories.

The explanatory variables were three, representing the work force, the MAR and Jacobs externalities. The population of residents aged 16–64 years (*Employees*) was used as the workforce. As mentioned before, the MAR externalities imply the regional specialization of an industry or the specialization in an industrial agglomeration area. I, therefore, used the coefficient of specialization or location quotient (LQ_{ir}), which is represented by the following equation, because it has often been used in previous studies as an indicator of the MAR externalities (Glaeser et al. 1992; Combes 2000).

$$LQ_{ir} = (E_{ir} / E_r) / (E_{in} / E_n) \tag{1}$$

where E_{ir} is the number of employees in an industry sector i in a region r,
E_r is the total number of employees in a region r,
E_{in} is the total number of employees in an industry sector i at the national level, and
E_n is the total number of employees in the all industry sectors at the national level.

The high proportion of experts with professional knowledge within the total employees is crucial for the MAR externalities, and thus the location quotient was frequently calculated and used in many case studies using the total number of employees in each industry sector and in all of the industry sectors (Carlino et al. 2007). Although the location quotients were used in this study, I did not use the number of employees because of the lack of employee data in the six categories of environment-related industries. Because of the constraints on the data, I evaluated the location quotients using the number of environment-related patents in each category and in all of the categories, and I used the total number of patents over all of the industries instead of the number of employees. A location quotient higher than 1 indicates a high degree of agglomeration of environment-related industries in a region, whereas a location quotient lower than 1 indicates a low degree of agglomeration.

The Hirschman-Herfindahl index is often used as an index representing the Jacobs externalities (Henderson 1997; de Lucio et al. 2002). In the present study, however, Simpson's diversity index (D) was employed instead of the Hirschman-Herfindahl index. The Simpson's diversity index is expressed as the following equation (Simpson 1949).

$$D = 1 - \sum_{i=1}^{s} P_i^2 \tag{2}$$

where P_i is the percentage of the number of a specie i in the total number of all of the species within a botanic community, and S is the number of species within a botanic community. I calculated the diversity index using the six categories of the environment-related industries as the species, and the 21 counties of Sweden as the botanic communities. When the diversity index score is higher than 1, one industry monopolizes in a county. In this case, the degree of diversity is very low. Conversely, when the score is close to null, the degree of diversity is very high.

Finally, regional agglomerations of the environment-related industries were examined using standard residuals derived from applications of the multiple regression analysis.

3. LOCATIONS OF ENVIRONMENT-RELATED INDUSTRIES

The following subsections describe the regional locations of the environment-related industries observed for each of the six categories of environment-related technologies. Before identifying these locations, I briefly note the agglomerations of all of the high-tech industries and all of the environment-related industries.

3.1 All of the High-Tech Industries

The analysis of regional patent acquisitions, which indicate the locations of high-tech industries, showed that large urban areas where ICT and biotechnology industries are agglomerated share the top spots on the list <Table 2>. The San Jose-San Francisco area including Silicon Valley is first, and other large urban areas such as Tokyo, New York, Boston, Los Angeles, Kanagawa (Yokohama) and Osaka follow. These are urban areas where headquarters of globally expanding/expanded ICT, biotechnology and other high-tech multinational companies are situated. It is noteworthy that no Chinese cities are named in this top-20 list, and China is ranked at eighth place regarding the total number of all patents by country. Although large urban areas are dominant in this list, medium-sized urban areas such as Noord Brabant with Eindhoven in Netherlands, where Philips' headquarters is located, also possess a large number of patents. This could be related to an agglomeration of the existing industries.

Table 2. Top 20 regions for agglomerations of high-tech industries

Rank	Region	No. of patents (1998-2008)	Share in the world (%)	Accumulated share in the world (%)
1	US146: San Jose-San Francisco-Oakland - CA	57,262.5	4.29	4.29
2	JPC13: Tokyo	55,680.0	4.17	8.47
3	US118: New York-Newark-Bridgeport - NY-NJ-CT-PA	43,729.8	3.28	11.75
4	US022: Boston-Worcester-Manchester - MA-NH	34,532.0	2.59	14.34
5	US097: Los Angeles-Long Beach-Riverside - CA	25,796.9	1.93	16.27
6	JPC14: Kanagawa	22,489.4	1.69	17.96
7	JPF27: Osaka	21,849.9	1.64	19.59
8	US145: San Diego-Carlsbad-San Marcos - CA	20,128.4	1.51	21.10
9	NL41: Noord-Brabant	19,911.2	1.49	22.60
10	US109: Minneapolis-St. Paul-St. Cloud - MN-WI	19,009.7	1.43	24.02
11	US032: Chicago-Naperville-Michigan City - IL-IN-WI	17,163.5	1.29	25.31
12	US127: Philadelphia-Camden-Vineland - PA-NJ-DE-MD	16,241.5	1.22	26.53
13	DE93: München	15,035.8	1.13	27.65
14	DE72: Stuttgart	13,999.9	1.05	28.70
15	US174: Washington-Baltimore-N. Virginia - DC-MD-VA-WV	13,743.9	1.03	29.73
16	KR011: Seoul	13,734.9	1.03	30.76
17	KR013: Gyeonggi-do	13,226.8	0.99	31.76
18	US075: Houston-Baytown-Huntsville - TX	12,468.4	0.93	32.69
19	US152: Seattle-Tacoma-Olympia - WA	11,913.9	0.89	33.58
20	JPE23: Aichi	11,832.7	0.89	34.47

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3.2 All Environment-related Patents

The regional acquisitions of all environment-related patents differ from those of all of the patents <Table 3>. Regarding the acquisition of all the environment-related patents, many regions in the U.S., where the ICT and biotechnology industries are accumulated, are at lower ranks compared to their ranks for all the patents. Conversely, areas in which there are transportation equipment companies related to Category E in the OECD classification rise in this ranking. Detroit—where the Big Three auto manufacturers are situated, Saitama (Honda), Regensburg (BMW), and Ibaraki (Hitachi Construction Machinery, or HCM)—is the example.

3.3 Category A: General Environment Management

Regarding the locations of the Category A, the environment-related patents are quite similar to those of the all-environment-related patents <Table 4>. There are slight changes in the high-ranking spots, but no replacement up to the 15th

Table 3. Top 20 regions for the total number of environment-related patents (six OECD categories)

Rank	Region	No. of patents (1998-2008)	Share in the world (%)	Accumulated share in the world (%)
1	DE72: Stuttgart	3,485.1	4.99	4.99
2	JPE23: Aichi	3,234.3	4.63	9.62
3	JPC13: Tokyo	2,387.6	3.42	13.03
4	JPC14: Kanagawa	1,434.8	2.05	15.09
5	US146: San Jose-San Francisco-Oakland - CA	1,344.2	1.92	17.01
6	US118: New York-Newark-Bridgeport - NY-NJ-CT-PA	1,204.2	1.72	18.73
7	JPF27: Osaka	1,101.5	1.58	20.31
8	US047: Detroit-Warren-Flint - MI	976.4	1.40	21.71
9	JPC11: Saitama	944.1	1.35	23.06
10	US097: Los Angeles-Long Beach-Riverside - CA	881.2	1.26	24.32
11	US022: Boston-Worcester-Manchester - MA-NH	869.1	1.24	25.56
12	NL41: Noord-Brabant	852.2	1.22	26.78
13	DE90: Regensburg	712.8	1.02	27.80
14	US109: Minneapolis-St. Paul-St. Cloud - MN-WI	665.4	0.95	28.76
15	DE93: München	659.1	0.94	29.70
16	US032: Chicago-Naperville-Michigan City - IL-IN-WI	656.1	0.94	30.64
17	US127: Philadelphia-Camden-Vineland - PA-NJ-DE-MD	568.5	0.81	31.45
18	US075: Houston-Baytown-Huntsville - TX	539.3	0.77	32.23
19	JPC08: Ibaraki	521.7	0.75	32.97
20	KR011: Seoul	506.8	0.73	33.70

Table 4. Top 20 regions for patents in OECD Category A: General Environment Management

Rank	Region	No. of patents (1998-2008)	Share in the world (%)	Accumulated share in the world (%)
1	JPC13: Tokyo	897.1	3.52	3.52
2	JPE23: Aichi	818.2	3.21	6.74
3	DE72: Stuttgart	540.8	2.12	8.86
4	US118: New York-Newark-Bridgeport - NY-NJ-CT-PA	525.4	2.06	10.93
5	US109: Minneapolis-St. Paul-St. Cloud - MN-WI	403.8	1.59	12.52
6	JPC14: Kanagawa	396.0	1.56	14.07
7	JPF27: Osaka	362.4	1.42	15.50
8	US022: Boston-Worcester-Manchester - MA-NH	325.0	1.28	16.77
9	US146: San Jose-San Francisco-Oakland - CA	320.3	1.26	18.03
10	US097: Los Angeles-Long Beach-Riverside - CA	314.7	1.24	19.27
11	US032: Chicago-Naperville-Michigan City - IL-IN-WI	311.6	1.22	20.49
12	JPC11: Saitama	292.4	1.15	21.64
13	US075: Houston-Baytown-Huntsville - TX	264.8	1.04	22.68
14	KR011: Seoul	248.3	0.98	23.66
15	US127: Philadelphia-Camden-Vineland - PA-NJ-DE-MD	221.5	0.87	24.53
16	DE44: Köln	213.3	0.84	25.36
17	KR013: Gyeonggi-do	211.8	0.83	26.20
18	US047: Detroit-Warren-Flint - MI	210.4	0.83	27.02
19	US011: Atlanta-Sandy Springs-Gainesville - GA-AL	175.6	0.69	27.71
20	JPE21: Gifu	173.8	0.68	28.40

place. Below the 16th rank, only Gyeonggi-do, Atlanta and Gifu are new to the top 20. However, each of these areas has less than one percent of the market share. These locations might thus contribute less to the global locations of environment-related industries in Category A.

3.4 Category B: Energy Generation from Renewable and Non-Fossil Sources

Concerning the regional distributions of the Category B, the environment-related patents, the regions situated at lower than the 10th rank differ from those of Category A and from the all-environment-related patents <Table 5>. The four regions in the 10th, 13th, 17th and 19th ranks are located in the Jutland peninsula, Denmark. Cooke (2008) revealed that wind turbine clusters were established in these regions. It can be inferred that various technologies related to wind turbines have been created and developed among companies in these clusters. Unlike Denmark, although Spain and China share high ranks in the country

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Table 5. Top 20 regions for patents in OECD Category B: Energy Generation from Renewable and Non-Fossil Sources

Rank	Region	No. of patents (1998-2008)	Share in the world (%)	Accumulated share in the world (%)
1	US146: San Jose-San Francisco-Oakland - CA	725.0	5.20	5.20
2	JPC13: Tokyo	432.8	3.10	8.31
3	US097: Los Angeles-Long Beach-Riverside - CA	277.1	1.99	10.29
4	US022: Boston-Worcester-Manchester - MA-NH	272.9	1.96	12.25
5	JPF27: Osaka	250.4	1.80	14.05
6	JPC14: Kanagawa	203.1	1.46	15.51
7	US118: New York-Newark-Bridgeport - NY-NJ-CT-PA	192.7	1.38	16.89
8	US127: Philadelphia-Camden-Vineland - PA-NJ-DE-MD	154.3	1.11	18.00
9	US047: Detroit-Warren-Flint - MI	152.0	1.09	19.09
10	DK042: Østjylland	148.3	1.06	20.15
11	US045: Denver-Aurora-Boulder - CO	146.4	1.05	21.20
12	KR011: Seoul	129.5	0.93	22.13
13	DE12: Ost-Friesland	129.4	0.93	23.06
14	DE93: München	127.2	0.91	23.97
15	AU105: Sydney - NSW	113.2	0.81	24.78
16	US133: Raleigh-Durham-Cary - NC	106.5	0.76	25.55
17	DK032: Sydjylland	102.2	0.73	26.28
18	KR013: Gyeonggi-do	101.1	0.72	27.00
19	DK041: Vestjylland	94.2	0.68	27.68
20	US174: Washington-Baltimore-N.Virginia - DC-MD-VA-WV	92.7	0.66	28.34

patent profile (8th with 2.6 percent and 9th with 2.5 percent, respectively), it would not be concluded that the environment-related industries in Category B were regionally concentrated in Spain and China. In addition, similar to the Danish wind turbine clusters, it is surmised that the environment-related technologies might be derived from the existing oil and gas industries when energy resources were diversified from fossil fuel to renewable energy in Denver, Colorado (11th) and Sydney (15th).

3.5 Category C: Combustion Technologies with Mitigation Potential

As regards the OECD Category C, the large urban areas situated in the higher places in <Table 6> are rather similar to those in the case of all the environment-related patents, whereas the regions in the lower ranks in this table are different. Regions in the top spots are located mainly in large urban areas, and their positions in this table are higher than

Table 6. Top 20 regions for patents in OECD Category C: Combustion Technologies with Mitigation Potential

Rank	Region	No. of patents (1998-2008)	Share in the world (%)	Accumulated share in the world (%)
1	JPC13: Tokyo	94.4	4.98	4.98
2	US075: Houston-Baytown-Huntsville - TX	79.0	4.17	9.15
3	US118: New York-Newark-Bridgeport - NY-NJ-CT-PA	55.8	2.94	12.09
4	DE86: Industrieregion Mittelfranken	46.9	2.47	14.56
5	NL32: Noord-Holland	43.0	2.27	16.83
6	US097: Los Angeles-Long Beach-Riverside - CA	41.1	2.17	19.00
7	US022: Boston-Worcester-Manchester - MA-NH	32.6	1.72	20.72
8	US032: Chicago-Naperville-Michigan City - IL-IN-WI	31.1	1.64	22.36
9	US072: Hartford-West Hartford-Willimantic - CT	30.7	1.62	23.98
10	US146: San Jose-San Francisco-Oakland - CA	27.2	1.44	25.41
11	CH033: Aargau	25.8	1.36	26.77
12	JPC14: Kanagawa	24.8	1.31	28.08
13	JPF28: Hyogo	24.6	1.30	29.38
14	SE110: Stockholms län	19.7	1.04	30.42
15	US023: Buffalo-Niagara-Cattaraugus - NY	18.8	0.99	31.41
16	DE41: Duisburg/Essen	17.7	0.93	32.34
17	DE93: München	17.2	0.91	33.25
18	US174: Washington-Baltimore-N.Virginia - DC-MD-VA-WV	15.7	0.83	34.08
19	US121: Orlando-The Villages - FL	15.5	0.82	34.89
20	FR105: Hauts-de-Seine	15.4	0.81	35.71

their positions in Table 3. These regions include Tokyo, Houston, Los Angeles, Boston and Chicago. Hyogo (13th), Stockholm (14th) and Duisburg-Essen (16th) are newly entered as top-20 regions. KOBELCO's and Thyssen Krupp's headquarters are located in Hyogo (Kobe, Japan) and Duisburg-Essen, Germany, respectively. Metal industries, especially steel industries, are accumulated in these two areas. It may be that cogeneration system-related technologies were established using waste heat from metal industry plants. In contrast, technologies concerned with district heating and power systems have accumulated in Stockholm. It is inferred that the accumulations of these technologies enabled these three regions to rise in the ranks of patents held.

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3.6 Category D: Technologies Specific to Climate Change Mitigation

Just like locational trends in the case of all the environment-related patents, the environment-related industries in Category D are concentrated mainly in large urban areas <Table 7>. Moreover, industries in this category are highly concentrated in Paris and its surrounding regions: Paris (14th), Lorraine (16th) and Hauts-de-Seine (17th). This might be closely connected to the accumulation of French companies around Paris with high environmental-related technologies such as those concerning the collection and savings of greenhouse gases, especially carbon dioxide capture and storage (CCS).

Table 7. Top 20 regions for patents in OECD Category D: Technologies Specific to Climate Change Mitigation

Rank	Region	No. of patents (1998-2008)	Share in the world (%)	Accumulated share in the world (%)
1	US118: New York-Newark-Bridgeport - NY-NJ-CT-PA	87.7	5.53	5.53
2	US075: Houston-Baytown-Huntsville - TX	72.6	4.57	10.10
3	US146: San Jose-San Francisco-Oakland - CA	67.0	4.22	14.32
4	JPC13: Tokyo	51.4	3.24	17.56
5	US097: Los Angeles-Long Beach-Riverside - CA	44.2	2.78	20.34
6	NL32: Noord-Holland	36.3	2.29	22.62
7	US022: Boston-Worcester-Manchester - MA-NH	30.0	1.89	24.51
8	US127: Philadelphia-Camden-Vineland - PA-NJ-DE-MD	29.1	1.83	26.35
9	JPC14: Kanagawa	29.1	1.83	28.18
10	US032: Chicago-Naperville-Michigan City - IL-IN-WI	28.8	1.82	30.00
11	US023: Buffalo-Niagara-Cattaraugus - NY	27.3	1.72	31.72
12	JPE23: Aichi	27.0	1.70	33.41
13	US045: Denver-Aurora-Boulder - CO	26.1	1.64	35.05
14	FR101: Paris	22.1	1.39	36.45
15	DE66: Rheinpfalz	21.4	1.34	37.79
16	FR716: Rhône	20.4	1.28	39.08
17	FR105: Hauts-de-Seine	17.9	1.13	40.21
18	NL33: Zuid-Holland	17.7	1.11	41.32
19	JPF27: Osaka	16.6	1.04	42.36
20	US040: Columbus-Marion-Chillicothe - OH	15.7	0.99	43.35

3.7 Category F: Emission Abatement and Fuel Efficiency in Transportation

Unlike other categories, the distribution of the environment-related industries in Category F is closely related to the locations of the automobile industry and construction machinery <Table 8>. Stuttgart (Daimler-Benz and Porsche), Aichi (Toyota), Regensburg (BMW), Peoria (Caterpillar), Västra Götalands län (Volvo), Hauts-de-Seine (Renault), Osaka (Daihatsu), Yvelines (Peugeot and Citroen), Braunschweig (Volkswagen), Ibaraki (Hitachi Construction Machinery) and Shizuoka (Honda, Yamaha and Suzuki) are examples of this category. It is thus evident that some Category F regions are classified into large urban areas, but some are not.

Table 8. Top 20 regions for patents in OECD Category F: Emissions Abatement and Fuel Efficiency in Transportation

Rank	Region	No. of patents (1998-2008)	Share in the world (%)	Accumulated share in the world (%)
1	DE72: Stuttgart	2,830.9	14.40	14.40
2	JPE23: Aichi	2,290.2	11.65	26.05
3	DE90: Regensburg	601.2	3.06	29.11
4	US047: Detroit-Warren-Flint - MI	543.0	2.76	31.88
5	JPC11: Saitama	489.0	2.49	34.36
6	JPC14: Kanagawa	476.2	2.42	36.79
7	JPC13: Tokyo	410.4	2.09	38.88
8	US126: Peoria-Canton - IL	273.3	1.39	40.27
9	SE232: Västra Götalands län	258.7	1.32	41.58
10	DE93: München	249.6	1.27	42.85
11	FR105: Hauts-de-Seine	227.8	1.16	44.01
12	DE79: Bodensee-Oberschwaben	217.5	1.11	45.12
13	JPF27: Osaka	213.9	1.09	46.21
14	US118: New York-Newark-Bridgeport - NY-NJ-CT-PA	211.8	1.08	47.28
15	FR103: Yvelines	204.7	1.04	48.32
16	DE22: Braunschweig	188.0	0.96	49.28
17	DE51: Rhein-Main	173.9	0.88	50.17
18	JPC08: Ibaraki	171.6	0.87	51.04
19	US032: Chicago-Naperville-Michigan City - IL-IN-WI	171.4	0.87	51.91
20	JPC22: Shizuoka	170.9	0.87	52.78

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3.8 Category G: Energy Efficiency in Building and Lighting

As for the locations of the environment-related industries in Category G, they too are located chiefly in large urban areas <Table 9>. Outside the large urban areas, regions where electrical machinery industries are agglomerated are also present among the top 20 regions. Examples are Aachen (6th), Gyeonggi-do (12th), where Samsung's and LG's headquarters are located, Cambridge (16th), where IT industries are agglomerated, and Berlin (18th), where Siemens is situated.

The results in all six of the OECD categories revealed that the most of the existing environment-related industries are located in large urban areas. In the next section, the impacts of externalities derived from urban populations are examined in a case study of Sweden.

4. KNOWLDGE SPILLOVER EFFECTS

The multiple regression analysis elucidated that the MAR externalities were dominant regarding agglomerations of the environment-related industries in Sweden <Table 10>. The coefficients of determination are more than 0.7 in the six categories. All of the coefficients are significant at the 1% level, indicating that this multiple regression consisting of three variables produced reliable results. Regarding the individual variables, it can be seen in the table that the number of employees representing the city size is significant at the 1% level in all six categories. The work force had positive effects on accumulations of the environment-related industries, as all of the values are positive. Except for Category A, the MAR exter-

Table 9. Top 20 regions for patents in OECD Category G: Energy Efficiency in Building and Lighting

Rank	Region	No. of patents (1998-2008)	Share in the world (%)	Accumulated share in the world (%)
1	NL41: Noord-Brabant	698.7	9.51	9.51
2	JPC13: Tokyo	501.6	6.83	16.35
3	JPC14: Kanagawa	305.5	4.16	20.51
4	JPF27: Osaka	245.7	3.35	23.85
5	JPC12: Chiba	218.8	2.98	26.83
6	DE45: Aachen	163.4	2.23	29.06
7	DE93: München	143.6	1.96	31.01
8	US118: New York-Newark-Bridgeport - NY-NJ-CT-PA	130.7	1.78	32.79
9	JPC08: Ibaraki	103.2	1.41	34.20
10	US022: Boston-Worcester-Manchester - MA-NH	101.4	1.38	35.58
11	JPC11: Saitama	98.9	1.35	36.93
12	KR013: Gyeonggi-do	92.8	1.26	38.19
13	US139: Rochester-Batavia-Seneca Falls - NY	92.6	1.26	39.45
14	US146: San Jose-San Francisco-Oakland - CA	82.2	1.12	40.57
15	US097: Los Angeles-Long Beach-Riverside - CA	80.8	1.10	41.67
16	UKH12: Cambridgeshire CC	77.9	1.06	42.73
17	US035: Cleveland-Akron-Elyria - OH	77.0	1.05	43.78
18	DE30: Berlin	76.8	1.05	44.83
19	KR011: Seoul	75.0	1.02	45.85
20	US127: Philadelphia-Camden-Vineland - PA-NJ-DE-MD	71.4	0.97	46.82

Table 10. Results of the multiple regression model examining the effects of the MAR and Jacobs externalities on agglomerations of environment-related industries for the OECD categories

Category	*Employees*		*LQ*		*D*	R^2	
A	1.305E-04	***	-3.778		-29.050	0.951	***
B	3.530E-05	***	6.661	***	-4.982	0.822	***
C	1.272E-05	***	0.849	**	-0.449	0.810	***
D	3.224E-06	***	0.287	***	-0.304	0.707	***
F	1.512E-04	***	35.871	**	-63.637	0.776	***
G	1.379E-05	***	1.202	***	-1.749	0.933	***

Note : *LQ*: Location quotient; *D*: Simpson's diversity index; R^2: Coefficient of determination.
*** p<0.01; ** p<0.05; * p<0.1.

Table 11. Standardized residuals in the 21 counties of Sweden by OECD category

County	Category A: General Environment Management	Category B: Energy Generation from Renewable and Non-Fossil Sources	Category C: Combustion Technologies with Mitigation Potential	Category D: Technologies Specific to Climate Change Mitigation	Category F: Emission Abatement and Fuel Efficiency in Transportation	Category G: Energy Efficiency in Building and Lighting
Stockholm			2.552			1.735
Uppsala		2.212				
Södermanland						2.041
Östergötland						
Örebro						
Västmanland		1.432				
Jönköping						
Kronoberg	1.134					
Kalmar						
Gotland						
Blekinge						
Skåne				2.761		
Halland				1.094		
Västra Götaland	1.228			1.490	3.096	
Värmland						
Dalarna						
Gävleborg						
Västernorrland						
Jämtland						
Västerbotten						
Norrbotten						

Note: The figures, which are more than one, are only shown in this table.

nalities positively influenced agglomerations of the environment-related industries because the location quotient representing regional specialization is significant at the 5% level at least in each category, and they have positive signs. Unlike the previous two variables, the Simpson's diversity indices are negative. Since a high score of this index indicates a low degree of diversity, the diversity, namely the Jacobs externalities, positively affected agglomeration of the environment-related industries in all categories. However, these indices are not significant at the 10% level in either category. This indicates that the Jacobs externalities did not affect the agglomeration of environment-related industries in Sweden. In sum, only the MAR externalities positively influenced the industry agglomeration in Sweden.

The findings resulted from this study are consistent with two points made by Beaudry and Schiffauerova (2009). Namely, (1) the MAR externalities are dominant in analyses using the broad industry classification data, in cases in which innovation is used as a dependent variable, and (2) only the MAR externalities affect the industry agglomerations in Sweden.

The standard residuals derived from the present multiple regression analysis revealed that the environment-related industries are concentrated in large urban areas in Sweden. These areas are Stockholm, Västra Götaland and Skåne counties, the cores of which are Stockholm, Gothenburg and Malmå cities, respectively <Table 11>. Stockholm county has the largest population in Sweden, while Västra Götaland and Skåne counties possess the second and third largest population, respectively. Only the standard residuals with 1.0 and above are shown in this table. The Stockholm county has the maximum in Category C, while the Västra Götaland county has the maximum in Categories A and F. The Skåne county has the highest score in Category D, while Uppsala county possessing the fourth largest urban area has the highest in Category B. Except for Category G, in which Södermanland county has the maximum, it is revealed that the environment-related industries are agglomerated in large urban areas in Sweden. This finding also indicates the externality of population accumulation in the large urban areas on the agglomeration of environment-related industries.

5. CONCLUSIONS

Using the OECD patent statistic data, I attempted to identify the locations of the environment-related industries around the world and to estimate the impacts of the MAR and Jacobs externalities on the agglomeration of these industries due to population accumulation in large urban areas. The findings can be summarized as follows. First, the locations of these industries tended to be concentrated in large urban areas including New York, Los Angeles and Chicago in the United States, Tokyo and Kanagawa (Yokohama) in Japan, and Munich and Stuttgart in Germany. However, there were also exceptions to this general trend, such as regions in the Danish Jutland peninsula where technologies related to wind turbine energy are situated.

It was also revealed that both MAR and Jacobs externalities had positive impacts on the agglomeration of environment-related industries. This result is consistent with findings of previous studies. Only the MAR externalities affected the industry agglomerations in Sweden. In this study, it was also confirmed that the MAR externalities dominated in the industry agglomerations, when innovation was used as the dependent variable and categorized in the broad industry classification. The aforementioned findings derived from the present study, i.e. the global distribution of environmental industries and agglomeration drivers of them, contribute to giving an awaiting solution for some unsolved problems pertain to the green innovation.

Regarding the agglomeration of environment-related industries in the urban areas, there is an argument that the growth of environment-related industry basically relies on demands for these environmental regulations in proportion to the level of standard of living and citizen consciousness for environment (Jaffe et al. 2002). Such institutional and social situations might lead to the agglomeration of environment-related industries chiefly in the urban areas of developed countries. However, it might be inferred that not institutional or social but economic circumstance, especially existing industries, has much influence on the agglomeration of these industries in urban area. In other words, cumulative effects are crucial for locations of the environment-related industries (Scott and Storper 1987; Storper 1988; Fujita et al. 1999). For example, a car manufacturer, namely Volvo, and its suppliers are accumulated in Gothenburg, Västra Götaland, Sweden. In Gothenburg, the environment-related industries in Category F, i.e. the emission abatement and fuel efficiency in transportation, were dominated in Sweden. As Storper and Scott (2009) stated, first, the specialised economic activities required high level of labour force, and then the newly established workers with high skills are endogenously yielded in the same region, especially the large cities (p. 162). Finally, new knowledge, innovation and industries are fermented in the process of cross-fertilisation of these workers (p. 163). Cooke

(2011) also termed such a newly born innovation from existing ones as transversal innovation. Category F of the environment-related industry, which was derived from car industry in Gothenburg, might be regarded as one of the transversal innovation clusters.

Although the present study identified the locations of environment-related industries and determinates of agglomerations of these industries, some unsolved research objectives remain. First, I employed patents as the only one indicator in the present study because they are good for measuring environment-related innovations (Oltra et al. 2009). However, the patent statistics have some shortcomings. The usefulness of the number of patents as an indicator on innovation is limited to some categories of environment-related industries because many environment-related industries are based on low-tech industries, and the characteristics of innovation strategy in low-tech industries are different from those in high-tech industries. To overcome such a research problem, I should combine other indicators with patent statistics for measuring environment-related industries in further studies. Second, the following were not taken into account regarding the agglomeration of environment-related industries: the agglomeration mechanisms of these industries, cooperation/competition among environment-related companies in the industry agglomerated areas, the effects of national and regional policies designed to encourage innovation, and cluster creations for these industries. In addition, methodological problems in evaluating the externalities were also left behind. One such problem is the limitations of the data, and another is the selection of the index/indicator. Here, I used the number of patents in the calculations of the location quotients, although the number of employees was often used in previous studies. It might be possible to first recalculate the number of employees in the smallest industry classification into the aforementioned seven categories of the environment-related industries, and then to use the recalculated numbers to evaluate the location quotients.

Further research is needed to employ such data to completely grasp the effects of the knowledge spillover. Although the location quotient and Simpson's diversity index represented the MAR and Jacobs externalities, respectively, in this study, Beaudry and Schiffauerova (2009) also pointed out that differences in externalities indicators caused varied results of effects on the industry agglomeration (p. 334). Like the necessity of using various measures, it is the same for dependent variables. Although I used the environment-related patents as the indicator representing innovation in this paper, research and development expenses in the environmental industry might be substitutable for this indicator. Future studies should take the aforementioned problems into account as we continue to attempt to identify the effects of knowledge spillover on the agglomeration of environment industries.

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