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A Parallel-Running-Type Growth Model in Asia: A Case of Clean Technology

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***Abstract*—A significant structural change in the pattern of economic development in Asian countries has been observed in recent years. In this situation, the existing studies on development economics, political science and innovation research cannot sufficiently explain the driving force and the mechanism of catch-up or economic growth. Therefore, it is now required to model this new type of economic development. In this paper we analyzed their scientific catch-up status using the data of four fields of clean technology to clarify the structural change. The results show that, while Asian countries have received matured technologies such as energy saving from advanced countries, they are accelerating research and development activities on emerging technologies. China, Korea and Singapore have caught up with advanced countries by conducting pioneering research for clean energy technologies to support their industrial development. On the other hand India has conducted relatively path-following catch-up. International collaboration still remains among the US, EU and Japan as it has been developed over a long time. However it is now changing with the emergence of Asian countries.**

I. INTRODUCTION

In fields such as development economics, political science, and innovation research, many studies have been conducted on the process in which the developing economies catch up with the advanced economies and on the convergence of the disparity. In particular, East Asia has been the central target of the researches [e.g., 1-9]. They can be classified according to the analysis targets: the studies on the production capabilities, those on the innovation capabilities, and those on the fundamentals and policies that affect these capabilities. Most of the studies use models in which the developing economies catch up with the advanced economies and gradually progress in the same development process as did the advanced economies. A typical model is the flying goose pattern of industrialization [10, 11]. Also, most of the papers focusing on the innovation capabilities are studies on the transfer or development of the industrial technologies, conducted on the basis of patent data. In contrast, there are few researches on the catch-up processes in the science. In the 21st century, however, we have seen many cases in which the developing economies became the center of the world-wide production in an extremely short period of time after a new product entered the market, such as LCD TVs, solar cells, and cellular phones [12].

In this situation, the existing studies cannot sufficiently explain the driving force and the mechanism of catch-up or economic growth [12]. Therefore, it is now required to model this new type of economic development. This paper aims to focus on the catch-up processes in the science and clarify the current situation. We will also discuss the differences among the economies or technologies and the causes for the differences, comparing four cases.

We focused on clean technology in this paper. The development and extensive use of efficient and inexpensive clean energy is the key to recent innovation. The term “clean energy” is widely used to mean environmentally friendly energy technologies. It includes renewable sources of energy, more efficient and effective use of existing energy resources, conservation and demand response, and related technologies. Governments are accelerating the introduction of schemes that provides incentives for the development of technology, such as the FIT (feed-in tariff), the RPS (renewable portfolio standard) and subsidies for the introduction of equipment for new energy. They are also scaling up their support for advanced research. These social demands and policies are accelerating clean energy research at an academic level, resulting in a rapid growth in the number of research papers [13, 14, 15].

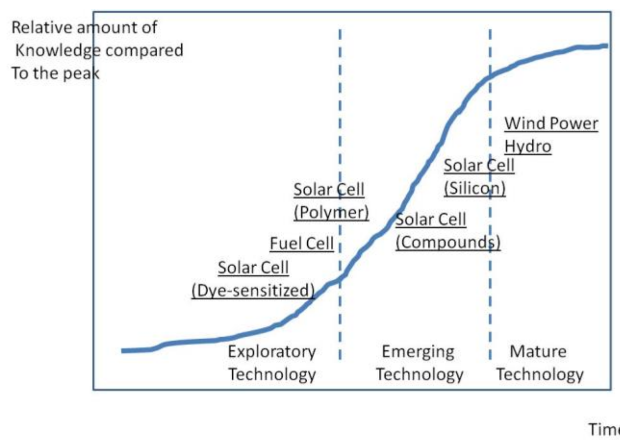

Figure 1. Maturity of Technologies

Specifically, we selected four of clean technologies as a subject to analysis. That is fuel cell, solar cell or Photovoltaic cell (PV), hydro and wind power. The hydro and wind power are the most-commercialized matured technology, while fuel cell and next generation solar cells (organics and dye-sensitized cell) are new technologies that have just started commercialization or not commercialized (see Figure 1). Therefore, the set of clean technologies is an appropriate theme for discussing whether the technical maturity causes a difference in the development strategy.

II. METHODOLOGY

First of all, for each type of clean technologies we clarify the research capabilities in major developing economies and the partner relationship between the areas, using numerous paper data, and then compare the types. The first step is to collect the data of the knowledge domains. We collect bibliometric data from the Science Citation Index Expanded (SCI-EXPANDED), the Social Sciences Citation Index (SSCI), and the Arts & Humanities Citation Index (A&HCI) compiled by the Institute for Scientific Information (ISI), which maintains citation databases covering thousands of academic journals and offers bibliographic database services, because these are three of the best sources for bibliometric data.

Second, we calculated the number and share of the papers written in the major economies for each technology.

Third, we create research network diagram by referring to the same database used for the creation of academic landscape, and for the extraction of data related to organisational affiliation of authors, geographical location of such organisations and co-authorships. Two types of data structure are developed: the data of research competency and of co-authorship. The data of research competency is obtained from the number of papers in each country or organization. The data of co-authorship is led by calculating all combinations of co-authors based on information about the author's organization [12, 15]. For example, if one paper is written by four different authors, and each author belongs to different organizations, the paper is considered to include six co-authorship relations. In addition, a co-authorship is defined as an international co-authorship if the authors belong to organizations in different countries. Authors in co-authored papers are not weighed by the order listed. Then, the data is visualized as a "research network diagram" with the author's organization as a node and co-authorship relation as a link between the nodes. In the diagram, organizations are grouped into the country they belong. In addition, combinations of economies that have more co-authorship relations are identified. The hub of international co-authorships is also obtained. The basic data of solar cell, fuel cell and wind power are based on our previous research of [12, 15, 16].

Then, comparing four fields, we discuss the nature of scientific catch-up and structure of international R&D collaboration,.

III. RESULTS

In first step for detecting corpus of each technology, papers with the terms "fuel cell", "photovoltaic cell" or "solar cell", "(power or electric*) near hydro) or hydro-power or hydropower or hydroelectric*" and "wind power* or wind energy or wind turbine or windmill* or wind mill* or wind farm or wind park or wind flow or wind industry* or wind resource or wind technolog* or offshore wind or onshore wind in their bibliographic information were selected from all the papers published between 1945 and current using the "SCI (Science Citation Index)" and "SSCI (Social Science Citation Index)", a database compiled by Thomson Reuters. Domain experts of each technologies support the identification of appropriate queries. The selected papers are defined as the papers on fuel cells, the papers on solar cells, the papers on hydro papers, and the papers on wind power, respectively. The papers with author information are then selected and grouped into four data sets: 12,264 papers on fuel cells, 35,323 papers on solar cells, 2,948 on hydro power and 2,517 papers on wind power. Although all four technologies are recognized as promising technologies for sustainable economy and society, the number of papers on hydro and wind power is significantly lower than that on fuel cells and solar cells. Information such as the publishing year, author's organization, and country of the organization is extracted from the data sets (see Table 1). Density of international collaboration per papers is high on the matured fields such as hydro and wind power. It is lowest in the field of solar cells.

Figure 2.(a) to (d) show the changes in the number of published in the top ten economies. We can see the rapid growth of publication in each filed. The growth rate of the papers on fuel cells is especially high.

TABLE 1 BASIC DATA OF THE 4 FIELDS

	Fuel cell	**Solar cell**	**Hydro Power**	**Wind Power**
# of papers with author information	12,264	35,323	2,948	2,517
# of countries wit in network	99	125	104	110
# of International citations	725	999	435	572
International citations/papers	0.059	0.028	0.148	0.227
Month/Year of latest data	Feb. / 2010	Aug. / 2009	Nov. / 2013	Mar. / 2011

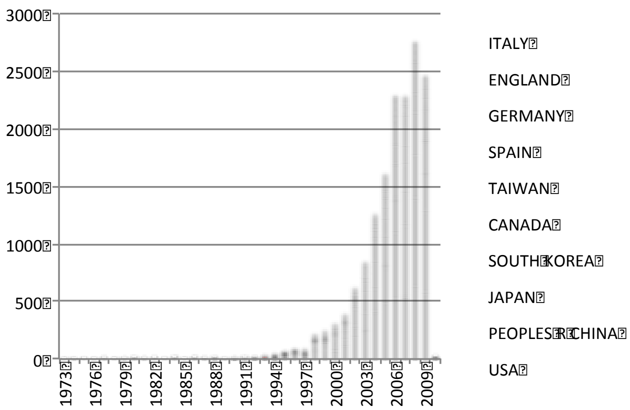

Figure 2(a) Number of publications (fuel cell)

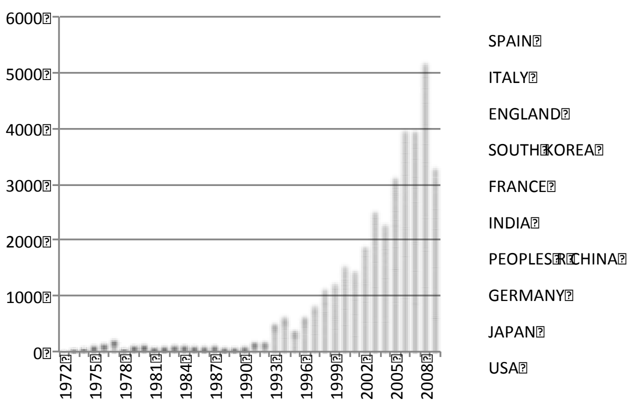

Figure 2(b) Number of publications (solar cell)

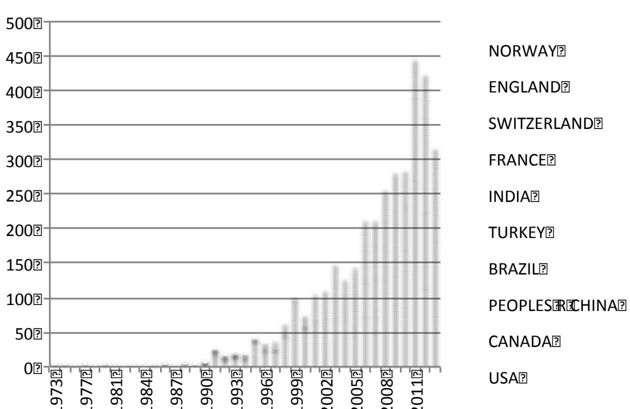

Figure2(c) Number of publications (hydro power)

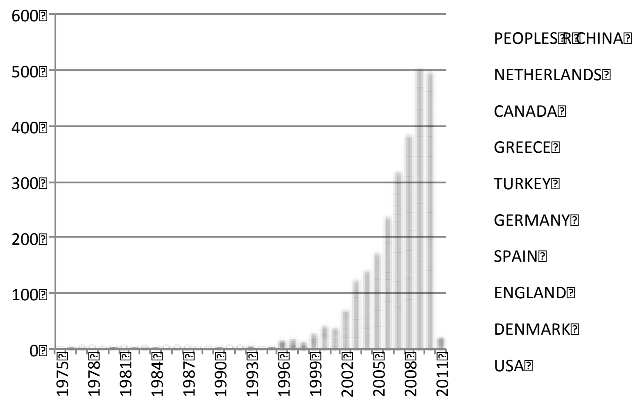

Figure 2(d) Number of publications (wind power)

We calculated the number and share of the papers per each technology written in the major economies. The high-ranking economies are the USA, Japan, Germany, China, India, Canada, France, England, South Korea, Singapore and Taiwan. The USA is top ranking for three of four fields. Since China, India, South Korea, Singapore and Taiwan are on the list, it is obvious that the Asian economies are catching up not only in the industrial technology, but also in the academic fields. The 3-pole structure in the USA, Japan and Europe have been gradually changing by the rise of Asia and Brazil. If we look at each area's share of the papers in each cluster, we see that China has more than 10% share in the field of fuel cell and PV. In particular the number of papers of China in the field of fuel cell is the highest in the world. However, China's share in the field of wind power remains about 3%. Based on the above data, China is highly competitive in the advanced fields of the immature technologies such as fuel shell and new generation solar cells. At present China does not have a strategy of placing emphasis on the infrastructure reinforcement for wind power for which China has the large production capacity.

In contrast, India has a relatively large share in the fields of PV and hydro and low shares in the clusters of fuel cell and wind power. Majority of the papers of India on solar cells are classified into silicon and compound cells which are relatively matured fields [12]. In contrast to emerging fields, India has a relative advantage in the matured field. South Korea has a large share in the field of fuel cell. Taiwan, like China, has a relatively high share in the field of fuel cell. Singapore is as well considering the size of economy and population. From these we see that the Asian economies can be classified into three categories. One is China, which have a top ranking share in emerging fields. The second are South Korea, Taiwan and Singapore, which have a relative advantage in the emerging fields. The third is India, which has an advantage in the matured fields.

Then we move to the analysis related to the research network diagram which reveals the structure of scientific cross-border collaboration. Figure 3.(a) to Figure 3.(d) show a visualized patterns of international collaboration of each filed. Research organizations in the same country are placed together and shown as a node. The size of each node shows number of papers written by authors from the country. Each link between two nodes of different countries indicates that there is a co-authorship between organizations in those countries. The breadth of each link indicates the number of co-authorships between countries. The diagram reveals that collaborative researches among three continents, Europe, USA and Asia, have become popular. Although four figures look similar, there are four major differences among these diagrams.

Firstly, the international collaboration of Asia (China, Korea and Japan) and the US for fuel cells is extremely strong. It is noteworthy that the US and Asia have developed close ties in the field of fuel cell technology, which is the most immature among the four technologies. Secondly, the strength of international collaboration differs within Asia. For fuel cells and solar cells, international collaboration mostly among Japan, China and Korea is strong. However for water and wind power technologies, collaboration in Asian regions is weak. Namely, collaborative activities in Asia are more active in more-emerging fields. Thirdly, major collaborative countries for water power generation are different from those for other power generation. Collaboration in this field is more active among the American countries such as the US, Canada and Brazil.

Fourthly, many African countries have joined the research network for solar cells. Their connection is mostly to European countries. This reflects the fact that there have been many pilot experiments conducted for rural electrification using solar cells.

A common characteristic in these power generation technologies, except hydro power, is that international research collaboration in Europe has developed. Also, compared to Europe, North America is more advanced for collaboration with Asia.

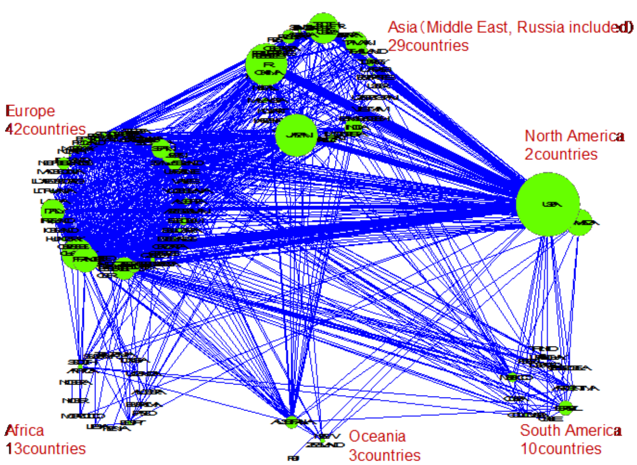

Figure3 (a) Network of International Collaboration (Fuel cell)

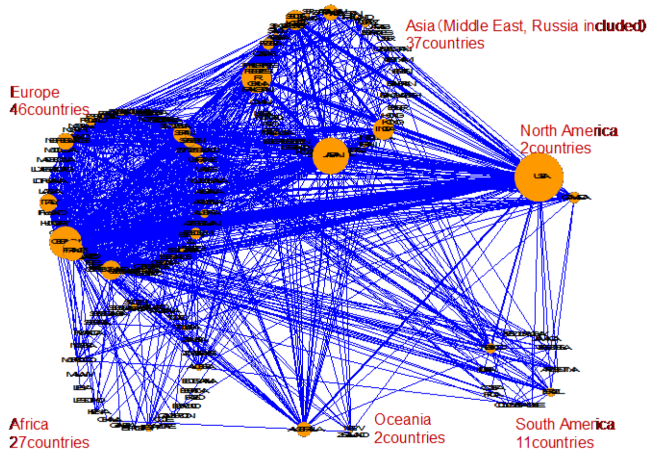

Figure 3(b) Network of International Collaboration (Photovoltaic(solar cell))

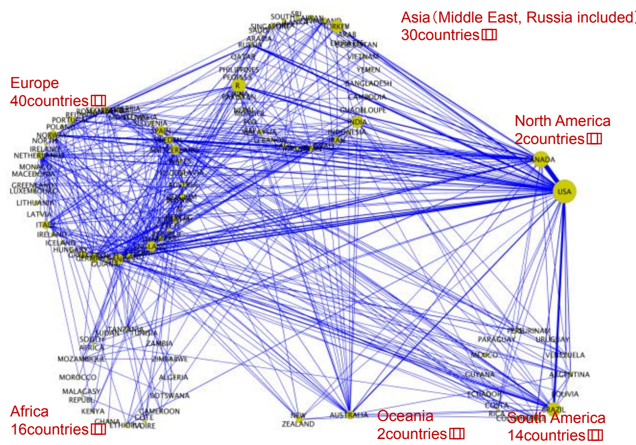

Figure3(C) Network of International Collaboration (Hydro power)

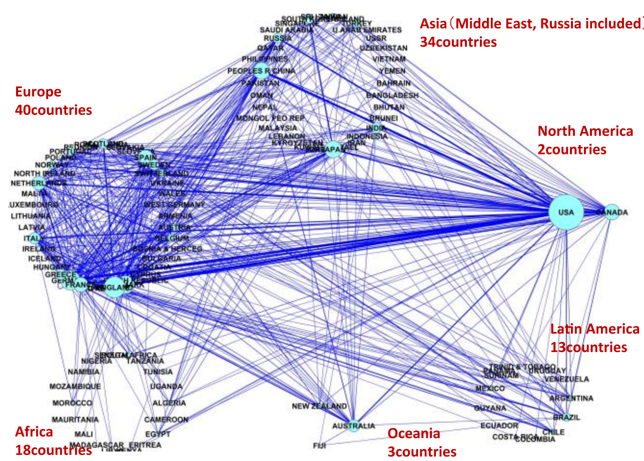

Figure 3(d) Network of International Collaboration (wind power)

IV. DISCUSSION

Asian economies are catching up with western countries with respect to science and technology. Major Asian countries, except India, emphasize research investment in emerging technologies. The progress of these countries is significantly supported by their own new technological development and product development (“path-finding progress”). On the other hand, India emphasizes improving existing technologies (“path-following progress”). Clearly, the science and technology policy of each country plays an important role in the rapid growth of the scientific and technological capability of Asia. Typical examples of government policies include Cool Earth 50 (Japan), Mid-term Development Plan for Renewable Energy (China), the Renewable Energy Law (China), New Growth Engine Vision (South Korea, One of the three pillars is green technology), RIE 2015 and STEP 2015(Singapore) and Solar Photovoltaic Program (India). Huge public R&D investment and governmental commitment in the growth potential of markets can also promote academic research. We observed that the emergence of an “innovation cycle [16]” where demands call for certain policies that enhance the knowledgebase and market, ultimately lead to an increased level of social attention and further strengthening of policies.

Major Asian countries (China, Korea, India, Singapore, etc.) play an important role in the international collaboration structure. For these major countries, technology transfer from advanced countries such as Europe, the US or Japan to developing countries is now an old vertical relationship model. The current international relationship is more horizontal. Conventional technology partnerships can still promote the transfer of existing, mature technology such as the transfer of energy-saving technologies and pollution prevention technologies from Japan to Asia. On the other hand, the strategy of the major Asian countries is not only to receive advanced technologies but also to develop technologies in emerging fields by themselves. However, research collaboration for water power or wind power generation technologies (Matured technologies) in which Japan is advanced is not expanded in Asia and could be expanded more in future. Although Asian countries are emerging in technology fields, the triangular relationship of the US, EU and Japan still remains for power generation technologies except water power. Also, international collaboration within Europe is very strong, which could reflect the Europe Framework Program or European Commission’s intention to actively use technologies for European integration.

For a detailed presentation of the collaboration relationship, international collaboration in each of the four power generation technology fields was studied from the information about the nationality of the authors of academic papers. Table 2 (a) to (d) show the top 20 numbers of international collaborations of multiauthored papers.

In the field of fuel cells, the number of collaborations between the US and China and that between the US and Korea rank in the top two. Not only with the US, China conducts research collaboration also with Japan, Singapore, Canada, and Germany and is enhancing its presence in the international community. To be more specific, China collaborates more with Canada and Singapore than with Germany, perhaps due to the network of Chinese residents in Canada. For solar cell technologies, the top three in the ranking are for the collaborations among the US, Europe and Japan, which indicates that the traditional triangular relationship among them still remains. This contrasts with international collaboration for another emerging technology, i.e. fuel cells. This is because the relationship among the US, Europe and Japan has developed over a long time more strongly for solar cells than for fuel cells. A typical example is the certification of conversion rates and Solar Cell Efficiency Tables [17] for providing information. Public agencies in the US, Japan, Germany, Italy, and Australia joined this system. On the other hand collaborative relationships between western countries (US and Europe) and China or Korea have been growing (South Korea-US in 5th rank, China-US in 8th rank, China-Japan in 9th rank, and South Korea-Japan in 10th rank). The number of multiauthored papers by authors of these countries is higher than that by authors of Japan and Germany. International collaboration relationships for solar cells are expected to change to be of the fuel cell type. In addition to these countries, India appears in the list of this field.

As for water power generation technologies, collaboration between the US and Canada is overwhelming and occupies 7% of the entire international collaboration for academic multiauthored papers. This percentage is the highest across the four fields. Major counties in the international collaboration for water power are Canada, Brazil and Chile, i.e. countries in the American continent. South-eastern Asian countries have less presence. For wind power generation technologies, the top six in the list are international collaboration with the US. In this collaboration, the US serves as a hub for the international collaboration network as it has a large amount of water power generation. Collaboration partners of the US are Germany, Canada, China, the UK, Denmark, and Russia. These countries are enthusiastic for the expansion of wind power generation in their own countries. In the wind power field, compared to cases in other technology fields, North European countries (Denmark, the Netherlands, and Sweden) have a stronger presence compared to Asia. North European countries are historically enthusiastic for wind power generation and hence path dependency is reflected in the international collaboration relationship.

TABLE 2(A) TOP 20 PAIRS (FUEL CELL)

Country1	Country 2	# of Collaborations	Share of Collaboraitons
USA	PEOPLES R CHINA	329	4%
USA	SOUTH KOREA	245	3%
USA	GERMANY	236	3%
USA	CANADA	230	3%
USA	JAPAN	193	2%
JAPAN	PEOPLES R CHINA	171	2%
SINGAPORE	PEOPLES R CHINA	127	2%
GERMANY	FRANCE	126	2%
USA	ITALY	125	2%
FRANCE	ITALY	122	2%
USA	FRANCE	121	2%
CANADA	PEOPLES R CHINA	118	2%
ENGLAND	USA	116	1%
PEOPLES R CHINA	GERMANY	94	1%
SWITZERLAND	USA	73	1%
GERMANY	ENGLAND	71	1%
PEOPLES R CHINA	SWEDEN	69	1%
SCOTLAND	ENGLAND	68	1%
SPAIN	FRANCE	67	1%
JAPAN	SOUTH KOREA	67	1%

TABLE 2(B) TOP 20 PAIRS (SOLAR CELL)

Country1	Country 2	# of Collaborations	Share of Collaboraitons
USA	GERMANY	523	5%
USA	JAPAN	222	2%
GERMANY	FRANCE	209	2%
SPAIN	GERMANY	169	2%
SOUTH KOREA	USA	163	2%
NETHERLANDS	GERMANY	153	1%
ENGLAND	GERMANY	150	1%
USA	PEOPLES R CHINA	147	1%
JAPAN	PEOPLES R CHINA	142	1%
SOUTH KOREA	JAPAN	139	1%
ITALY	FRANCE	139	1%
GERMANY	JAPAN	131	1%
SWITZERLAND	GERMANY	127	1%
ENGLAND	USA	123	1%
GERMANY	ITALY	121	1%
RUSSIA	GERMANY	118	1%
INDIA	SOUTH KOREA	118	1%
AUSTRIA	GERMANY	116	1%
ITALY	ENGLAND	113	1%
FRANCE	SPAIN	104	1%

TABLE 2(C) TOP 20 PAIRS (HYDRO POWER)

Country1	Country 2	# of Collaborations	Share of Collaboraitons
USA	CANADA	196	7%
BRAZIL	USA	82	3%
RUSSIA	USA	58	2%
USA	PEOPLES R CHINA	46	2%
USA	SWEDEN	40	2%
USA	TURKEY	40	2%
CANADA	NORWAY	40	2%
SWEDEN	CANADA	38	1%
FRANCE	USA	36	1%
PEOPLES R CHINA	CANADA	34	1%
ENGLAND	USA	34	1%
USA	AUSTRALIA	32	1%
FRANCE	BRAZIL	30	1%
CANADA	RUSSIA	30	1%
FINLAND	USA	30	1%
NETHERLANDS	USA	28	1%
ENGLAND	CHILE	24	1%
NORWAY	RUSSIA	24	1%
FRANCE	FRENCH GUIANA	24	1%
NORWAY	FRANCE	22	1%

TABLE2(D) TOP 20 PAIRS (WIND POWER)

Country1	Country 2	# of Collaborations	Share of Collaboraitons
GERMANY	USA	69	3%
CANADA	USA	59	2%
PEOPLES R CHINA	USA	57	2%
ENGLAND	USA	57	2%
DENMARK	USA	44	2%
RUSSIA	USA	36	1%
DENMARK	GERMANY	36	1%
FRANCE	USA	34	1%
ENGLAND	GERMANY	34	1%
JAPAN	USA	32	1%
NETHERLANDS	USA	31	1%
GERMANY	NETHERLANDS	31	1%
JAPAN	SOUTH KOREA	28	1%
ITALY	USA	27	1%
ENGLAND	SCOTLAND	24	1%
AUSTRALIA	USA	23	1%
ENGLAND	NETHERLANDS	22	1%
AUSTRIA	RUSSIA	22	1%
SWEDEN	USA	21	1%
DENMARK	ENGLAND	21	1%

V. CONCLUSION

In this study we analyzed the research capabilities and international collaboration relationships of various countries in four clean-energy technology fields using author information available from academic papers. The results show that, while Asian countries have been transferred matured technologies such as energy saving from advanced countries, they are accelerating research and development activities on emerging technologies. The emergence of an "innovation cycle" where demands call for certain policies that enhance the technological knowledge and market, ultimately lead to an increased level of social attention and further strengthening of polices.

The models of catch-up are significantly different across the countries or technologies. China, Korea and Singapore have caught up with advanced countries by conducting pioneering research for clean energy technologies to support their industrial development. A “parallel-running-type growth model [15, 16]” has thus been emerging in Asia. On the other hand India has conducted path-following catch-up.

International collaboration still remains among the US, EU and Japan as it has been developed over a long time. However it is now changing with the emergence of Asian countries. This change is particularly large in fuel cells, the emerging technology field showing the most rapid change. The international relationships becomes more and more horizontal in the emerging fields. Compared to advanced technologies, international collaboration for emerging technologies is not strong yet and hence will change largely in future. For other advanced clean energies such as water power or wind power, international collaboration is already strong compared to the number of academic papers in this area. Therefore the international collaboration structure varies depending on the clean energy. Collaboration within the American continent is relatively strong for water power generation, and collaboration for wind power centers on the US as a hub. In these relationships for water and wind, Asian countries have little presence.

Three major elements could affect the research capabilities and the international collaboration relationship of the countries: The national policy of science and technology, size of market, and historical path dependency.

The Asian development model described in this paper presents development that countries other than Japan have not experienced before. Also this development model is different from the Asian Miracle [1] modeled by the Word Bank or the flying goose pattern of industrialization. Many previous papers [e.g. 18, 19, 20] identified the significant role of technology, however, most of them didn't talked about the emergence of this type of development model. .The factors behind the model include accelerated technology transfer, releasing open innovation model [e.g.,21, 22], strengthened linkage between basic research and industrial technology [e.g., 23, 24], accumulated technologies, and market expansion, which together create a positive growth cycle. Growing Asian countries which will follow the development of China, South Korea, India and Singapore should take this new growth model into consideration when they draft their growth strategy and science and technology policy.

This new development model needs to be studied further. In future we will focus on individual research institutes and researchers and conduct a more detailed study using network indices of international joint authorship of academic papers.

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REFERENCES

[1] World Bank, *Main Report Vol.1 of the East Asian Miracle: Economic Growth and Public Policy*, A World Bank Policy Research Report, 1993. http://documents.worldbank.org/curated/en/1993/09/698870/east-asian-miracle-economic-growth-public-policy-vol-1-2-main-report

[2] Mathews, J. A., “Enhancing the role of universities in building national innovative capacity in Asia,” *World Development*, vol.35, pp. 1005-1020, 2007.

[3] Altenburg, T., H. Hubert and A. Stamm, “Breakthrough ? China’s and India’s Transition from production and innovation,” *World Development*, Vol.36, No.2, pp. 325-344, 2008.

[4] Kenny, C., “What’s not converging? East Asia’s relative performance in income, health and education,” *Asian Economic Policy review*, vol.3, pp. 19-37, 2008.

[5] Berkhout, F., D. Angel, A. J. Wieczorek, “Asian Development pathways and sustainable socio-technical regimes,” *Technological Forecasting and Social Change*, Vol.76, pp. 218-228, 2009.

[6] Tour, A., M. Glachant and Y. Meniere, “Innovation and international technology transfer: the case of the Chinese photovoltaic industry,” *Energy Policy*, vol.39, pp. 761-770, 2011.

[7] Lee, Y. H. and M. Y. Cheng, “Catching-up and technological progress of the ASEAN economies,” *Pacific Economic Review*, vol.16, No.2, pp. 236-254, 2011.

[8] Hu, M. C., “Technological innovation capabilities in the thin film transistor-liquid crystal display industries of Japan, Korea, and Taiwan, *Research policy*, vol.41, pp. 541-555, 2012.

[9] Jang, S.L., S. Lo and W.H. Chang, “How do latecomers catch up with forerunners? Analysis of patent and patent citations in the field of flat panel display technologies, Scientometrics, vol. 79,No.3,pp. 563-591, 2009.

[10] Linden, G., J Hart, S.A. Lenway and T.P. Murtha, “Flying geese as moving target: are Korea and Taiwan catching up with Japan in advanced displays?,” *Industry and Innovation*, vol.5, No.1, pp. 11-34, 1998.

[11] Schrank, A., “Foreign investors, flying geese, and the limits to export-led industrialization in the Dominican Republic,” *Theory and Society*, vol.32, pp. 415-443, 2003.

[12] Sakata, I. and H. Sasaki, "Scientific catch-up in Asian countries: a case for solar cell", *Natural Resources,* vol.4, pp.134-141, 2013.

[13] Shibata, N, Y. Kajikawa and I. Sakata, Extracting the commercialization gap between science and technology—Case study of solar cell, *Technological Forecasting and Social Change* vol.77 (7), pp.1147-1155, 2010.

[14] Shibata, N., Y. Kajikawa, I. Sakata, Assessing the gap between science and technology: Case study of secondary batteries, *Journal of Intellectual Property Association of Japan* vol.6 (3), pp.5-11, 2010.

[15] Sakata, I. H. Sasaki, N. Nakamura and Y. Kajikawa, “Maps of international research collaboration in renewable energy, " in *The Proceedings of the 6th Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems*, Dubrovnik, 25-29 September, 2011.

[16] Sakata, I. and H. Sasaki, “Bibliometric analysis of international collaboration in wind and solar energy,” *Journal of Sustainable Development of Energy, Water and Environment Systems*, vol.1 (3), pp.187-198, 2013.

[17] Green, M.A., K, Emery, Y. Hishikawa, W. Warta and E.D. Dunlop, “Solar cell Efficiency Tables Ver.43,” *Prog. Photovolt: Res. Appl.* vol.22, pp.1-9, 2014.

[18] Sun, Y. and D. Du, "Determinants of industrial innovation in China: Evidence from its recent economic census," *Technovation*, vol.30 (9-10), pp.540-550, 2010.

[19] Wang, T.- Y.-, and S.-C.- Chien, "The influences of technology development on economic performance - The example of ASEAN countries," *Technovation*, vol.27 (8), pp.471-488, 2007.

[20] Wang, T.-Y. , S.-C.- Chien and K. Chiang, "The role of technology development in national competitiveness- Evidence from South East Asian Countries," Technological Forecasting and Social Change, vol.74(8), pp.1357-1373, 2007.

[21] Kuang-Peng,H. and C. Christine, “The impact of open innovation on firm performance: the moderating effects of internal R&D and environmental turbulence,” *Technovation*, vol.33, pp.368-380, 2013.

[22] Berchicci, L., "Toward an open R&D system: internal R&D investment, external knowledge acquisition and innovative performance," *Research policy*, vol.42, pp.117-127, 2013.
[23] Narin, F., K. Hamilton and D. Olivastro, "The increasing linkage between U.S. technology and public science," *Research Policy*, Vol. 26, pp. 317-330, 1997.
[24] Narin, F. and D. Olivastro, "Status report: Linkage between technology and science," *Research Policy*, vol. 21, pp. 237-249, 1992.