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Abstract

The Kyoto Mechanisms, namely, the Clean Development Mechanism (CDM), Joint Implementation (JI), and International Emissions Trading (IET), were introduced primarily to help Annex I countries attain emissions reduction targets cost efficiently. In addition, the introduction of the CDM and JI were expected to promote international technology transfer of climate technologies. To what extent do the Kyoto Mechanisms contribute to the international diffusion of climate technologies? What are the main factors that influence the international diffusion of climate technologies under the Kyoto Mechanisms? The purpose of this study is to explore the answers to these two research questions based on a review of a growing number of studies on this topic, particularly on the CDM, as well as an analysis of the data on main technologies, host and investing countries of CDM and JI projects. The study found first that the effects of the CDM and JI on the international transfer of climate technologies are neither strong nor weak, and second that these effects vary by host country, technology type and host country's absorptive capacity of technology. One of main implications of this study is the necessity of empirical studies about credit-incentives on technology innovation.

Keywords: Clean Development Mechanism, climate technologies, international technology diffusion, international technology transfer, Joint Implementation, Kyoto Mechanisms

1. Introduction

Technology plays a vital role in climate change mitigation since it remarkably reduces the difficulties and costs of addressing climate change mitigation. The Kyoto Mechanisms, namely, the Clean Development Mechanism (CDM), Joint Implementation (JI), and International Emissions Trading (IET), were introduced under the Kyoto Protocol adopted in 1997 to help developed countries and economies in transition, known as Annex I countries of the United Nations Framework Convention on Climate Change (UNFCCC), to attain their emissions reduction targets cost efficiently[1]. In addition, these flexible mechanisms were introduced with the expectation that they would contribute to the international diffusion of climate change mitigation technologies (hereafter, climate technologies). As of August 1, 2015, the accumulated numbers of registered CDM and JI projects were 7,654 and 604, respectively (UNEP DTU Partnership). The Kyoto Mechanisms are credit-incentive mechanisms since they issue credits for use by Annex I countries and firms in these countries to offset their emissions and attain their emissions reduction targets at less cost rather than attaining the targets by themselves. Therefore, Annex I countries and firms have incentives to invest in CDM or JI projects since they can gain credits equivalent to the emissions reduced by the projects, while they have incentives to be engaged in IET since they can buy and sell credits in carbon market. Under the CDM, JI and IET, three types of credits are issued (METI, 2004, pp.44-45). The credits issued under the IET are Assigned Amount Units (AAUs). AAUs equivalent to the initial emissions allowance are allocated to Annex I countries according to their emissions targets. The credits issued under the CDM are Certified Emission Reductions (CERs). When emissions are additionally reduced by implementing emissions-reduction projects, for example, energy saving or afforestation projects, in non-Annex I countries (i.e., developing countries), CERs equivalent to the reduced emissions are issued and all or a part of the CERs are acquired by investing countries and firms of the projects. Host countries of CDM projects are non-Annex I countries while investing countries are Annex I countries. The credits issued under the JI are Emission Reduction Units (ERUs). When the emissions are additionally reduced by implementing the emissions reduction projects jointly by Annex I countries, ERUs equivalent to the reduced emissions are issued and all or a part of them are acquired by investing countries and firms. ERUs are issued by converting a part of AAUs initially allocated to host countries. One unit of CER/ERU/AAU is equal to one ton of CO_2 equivalent (tCO_2eq). The volume of AAUs accounts for no more than 0.6% of the total volume of allowances allocated under various emissions trading schemes (ETSs) in the world, including EU-ETS (World Bank, 2012).

[1] More precisely, there are so-called sink activities under the Kyoto Mechanisms. However, this study focuses on three mechanisms of the CDM, JI and IET, which are more relevant to the study topic.

To what extent do the Kyoto Mechanisms contribute to the international diffusion of climate technologies? What are the main factors that influence the international diffusion of climate technologies under the Kyoto Mechanisms? For example, is the availability of credits sufficient to incentivize countries/firms to invest in CDM/JI projects that appear to be good channels for the international technology transfer of climate technologies (hereafter, ITT)? Furthermore, is the availability of credits sufficient to incentivize countries/firms to be engaged in IET that appears to influence climate technology innovation? The answers to these questions must have important implications for the post-Kyoto frameworks. There are a growing number of studies on the contribution of the Kyoto Mechanisms to the international diffusion of climate technologies. However, most focus their analysis on only the CDM and its contribution to ITT. In addition, these studies show that there seems to be no straightforward answer about the contribution of the CDM to ITT. This study broadens the focus of most previous studies in order to provide policymakers with useful scientific information on the overall effect of the Kyoto Mechanisms on the international diffusion of climate technologies. The purpose of this study is to assess the effects of the Kyoto Mechanisms (the CDM, JI, and IET) on international technology diffusion, which is defined more broadly than ITT, based on analyzing the data and synthesizing the findings of existing empirical studies.

The rest of this paper is structured as follows. Section 2 discusses theoretical frameworks, including the factors influencing international technology diffusion and their applications to the credit-incentive mechanisms of the Kyoto Mechanisms. Section 3 discusses the methodology adopted in this study. Section 4 presents an overview of CDM and JI projects and IET using data. Section 5 discusses findings of a literature review. Finally, Section 6 concludes with a summary of the study results and their implications for future research and post-Kyoto frameworks.

2. Theoretical Frameworks

2.1. Factors influencing international technology diffusion

Technology diffusion occurs when technology innovation (a new product, new process, or new management method) is adopted within a country or across countries. According to Freeman (1992), there are four types of technology innovation: (1) incremental innovations, as occurred with car engines, (2) radical innovations, such as hybrid cars, (3) changes in the technological systems, as with a shift to a low-emission economy, and (4) changes of the techno-economic paradigm, as with the internet.

Technology diffusion across countries, that is, international technology diffusion, occurs when technology innovation in a country is transferred to and adopted in other countries. Although there seems to be no unified definition, this study defines ***international technology diffusion*** as a result of three processes, that is, ***technology innovation*** in technology-providing countries, ***international technology transfer*** from technology-providing countries to technology-receiving countries, and ***technology adoption*** in technology-receiving countries.

There are two main channels for ITT. One is a public channel. Official development assistance (ODA) and technical cooperation at municipal levels are examples of public channels. The other is a private channel. Trade, foreign direct investment (FDI), and licensing are examples of private channels (Schneider et al., 2008). In addition, networking among firms, researchers, and so on must be a good channel for ITT. Private-sector investment plays an important role in enhancing ITT because it accounts for the largest share of investment and financial flows for ITT (UNFCCC, 2007). FDI and imports of high-technology products and intermediate inputs play important roles in a country's increasing access to foreign technologies. However, ITT through these channels is not sufficient for international technology diffusion. Burns (2009, p.169) argues that "a country's technological absorptive capacity determines the extent to which these technologies are absorbed by domestic firms and incorporated into daily economic life."

This discussion suggests there are two main factors that influence international technology diffusion (i.e., causing ITT and its spread in technology-receiving countries). One factor is external, namely, exposure to foreign technologies through trade, FDI, ODA, municipal technical cooperation, licensing and networking. Though there are contrasting views on the role of intellectual property rights (IPR), developed countries view IPR as a driver of international technology diffusion (Dechezleprêtre, 2013). Appropriate regulations on intellectual property rights (IPR) might increase the chance of being exposed to foreign technologies because foreign firms do not have to worry that their technologies are copied in the countries where they are engaged in businesses. As a result, IPR regulations boost imports and FDI relating to new technologies. The other factor is domestic, namely, technological absorptive capacity, which could be enhanced by education for technological literacy, research & development activities, and so on. Without technological absorptive capacity, it is difficult to cause ITT to occur and spread in technology-receiving countries.

2.2. Credit-incentive mechanism as a driver of the international diffusion of climate technologies

As Subsection 2.1 mentioned, international technology diffusion involves technology innovation, ITT and technology adoption. Among them, ITT plays a crucial role in bridging gaps between a country where technologies are innovated and a country where they are adopted. The CDM and JI are expected to result in new technologies for sustainable development to developing countries (categorized as non-Annex I countries *without* emissions reduction obligations under the UNFCCC) and economies in transition (categorized as Annex I countries *with* emissions reduction obligations under the UNFCCC). The acquisition or transfer of credits generated by emissions reduction through CDM and JI projects makes it possible for developed countries (categorized alongside economies in transition as Annex I countries *with* emissions reduction obligations under the UNFCCC) to use the credits to meet their emissions reduction targets as investing countries in the projects. At the same time, it is possible that, through CDM and JI projects, developing countries as host countries of CDM projects and economies in transition as the main host countries of JI projects are exposed to — and adopt—foreign technologies as well as reduce domestic emissions. Therefore, both host and investing countries have incentives to participate in CDM and JI projects. As a result, it is expected that international diffusion of climate technologies is enhanced through CDM and JI projects. In addition, some "unilateral" projects can be implemented only by developing countries without the involvement of developed countries. Under the unilateral projects, host countries can acquire credits—CERs or ERUs. The other credit-incentive mechanism, IET, makes it possible for developed countries and economies in transition to sell and buy AAUs, which provide these countries with incentives for technology innovation.

To evaluate the overall effects of the Kyoto Mechanisms on the international diffusion of climate technologies, it is important to understand how the Kyoto Mechanisms incentivize technology innovation, ITT and technology adoption. In particular, credits issued under the Kyoto Mechanisms are supposed to play important roles as a driver of the international diffusion of climate technologies since the credits incentivize developed countries/firms to invest in CDM/JI projects and to be engaged in IET. As shown in Table 1, it is expected that CERs and ERUs incentivize developed countries and firms in the developed countries to invest in CDM and JI projects if such investment is less costly to reduce emissions than at home and it meets "additionality" criterion. Additionality is a condition particularly for CDM projects to be validated by a designated operational entity (DOE) and registered by the CDM executive board. Additionality requires that the project generates additional emissions reduction which otherwise could not happen (Chuo-Aoyama, 2005, p.256). On the other hand, developing countries/economies in transition and firms in these countries have incentives to host CDM or JI projects since they have access to new climate technologies and finance by hosting the projects. In addition, Table 1 shows that AAUs incentivize developed countries and economies in transition, and firms in these countries to enhance technology innovation because they can make profits if they can sell the credits or because they do not have to buy credits if they can reduce excess emissions at home at less cost than buying credits.

Table 1. Credit-incentives for Countries and Firms under the Kyoto Mechanisms

Mechanism	Credits gained/traded	Host country and firms in a host country	Investing country and firms in investing country
CDM	CERs	Has incentives to host projects since it is able to access foreign technologies and finance.	○ Has incentives to provide technology and finance since it is able to gain credits.
JI	ERUs	Has incentives to host projects since it is able to access foreign technologies and finance.	○ Has incentives to provide technology and finance since it is able to gain credits
Mechanism	Credits traded	Country and firms selling credits	Country and firms buying credits
IET	AAUs (CERs, ERUs)	○ Has incentives to promote technology innovation since it is able to sell credits.	○ Has incentives to promote technology innovation since it need not buy credits by reducing emissions by itself.

Notes: (1) The circle (○) in Table 1 indicates a credit-incentive. (2) Under IET, secondary CERs and ERUs can be traded among developed and developing countries and economies in transition.

There is an important issue in designing ETSs that is relevant to technology innovation. That is, "what facilitates technology innovation, emissions targets or efficiency targets?" Equation (1) is a simplified version of the well-known Kaya identity. Then, equation (2) is a logarithmic equation converted from equation (1). Equation (2) indicates that the change (%) in CO_2 emissions depends on the change (%) in CO_2 emissions from producing one unit of GDP and the change (%) in GDP. It is simple but has a clear message to how to address CO_2 emissions reduction in a country/firm. Equation (2) indicates that there are two ways to reduce emissions in a country/a firm. One is to lower CO_2 emissions per unit of GDP through technological progress in low-carbon technologies or energy-saving technologies. The other is to lower a country's GDP or a firm's production. Of course, there is a combination of the two alternatives. The Kaya identity has an important implication for the choice of target setting in designing IET, that is., whether the target should be set on the CO_2 emissions or emissions intensity. ETSs currently being implemented at municipal and provincial levels in China and the ETS at state level in India, what is called Perform, Achieve and Trade (PAT), adopt emissions-intensity as the target (PAT targets pollutants damaging human health, not CO_2).

$$CO_2\ emissions = CO_2\ emissions/GDP \times GDP \quad \text{(simplified Kaya Identity)} \tag{1}$$

$$\ln(CO_2\ emissions) = \ln(CO_2\ emissions/GDP) + \ln(GDP) \tag{2}$$

3. Methodology

There are a growing number of empirical studies that assess the contribution of the CDM to ITT. On the contrary, there are very few studies on the contribution of JI and IET. Particularly, there is no empirical study on the contribution of IET as far as the literature search in this study is concerned. Most of the studies on CDM use the data in project design documents (PDDs) available for each CDM projects including information on technology transfer. However, the data necessary to investigate the contribution of JI or IET are limited. To make up for this shortcoming, this study collected and analyzed the data on the JI and IET as well as the CDM, more specifically, the data on (1) countries from and to which technologies are more likely to be transferred under the CDM and JI, (2) technologies which are more likely to be transferred under the CDM and JI, and (3) the countries which are more likely to develop innovative technologies under IET. Furthermore, whether the Kyoto Mechanisms are successful in progressing the international diffusion of climate technologies depends on how they can incentivize stakeholders (countries, firms, and so on) to invent, transfer, or adopt technologies. This is crucial in assessing the credit-incentive mechanisms like the Kyoto Mechanisms. Therefore, this study analyzes whether the reviewed studies incorporate this point in their assessment. Analytical framework in this study is the following. It consists of two steps (Figure 1)

Figure 1. Analytical Framework

Step 1 examines the following points (based on data).

(1) The countries from and to which technologies are more likely to be transferred under the CDM and JI

(2) The technologies that are more likely to be transferred under the CDM and JI

(3) The technologies that are more likely to be innovated under IET.

⇓

Step 2 examines the following research questions (based on a literature review).

To what extent do the Kyoto Mechanisms contribute to the international diffusion of climate technologies?

What are the main factors that influence the international diffusion of climate technologies under the Kyoto Mechanisms?

4. Survey Results: Data Analysis

4.1. The Clean Development Mechanism and Joint Implementation

The CDM and JI are likely to play important roles as channels for ITT since investing countries/firms provide host countries with finance and technologies that would not otherwise be available. However, ITT does not necessarily take place in CDM and JI projects. For example, ITT does not occur when CDM projects are "unilateral" projects, which can be implemented only by host countries without the participation of investing countries (Haishutsuken torihiki Kenkyukai, 2007, pp.198-201). In unilateral projects, host countries provide finance and technologies by themselves. Another example is when the climate technology imported from an investing country through a CDM or JI project is not new for a host country. In this case, it cannot be said that ITT takes place through a CDM or JI project according to the definition of ITT (a more detailed discussion on the ITT definitions in Section 5).

Section 5 investigates the research questions, that is, "to what extent do the CDM and JI contribute to ITT?" and "what are the main factors that influence ITT under the CDM and JI?"—by reviewing the existing literature. The present section analyzes the data relevant to these questions. These are the data on the countries that receive and provide climate technologies through CDM and JI projects and on the project types (technology types) of CDM and JI projects. These data provide information on the countries that are likely to contribute to ITT through CDM and JI projects and on the technologies that are likely to be internationally transferred trough CDM and JI projects.

The CDM/JI Pipeline Analysis and Database of UNEP DTU Partnership includes data on the latest accumulated number of registered CDM projects by project type (27 in total) and by host country (114 non-Annex I countries in total). The data on investing countries of CDM projects (41 Annex I countries in total) are available from the KYOTO Mechanisms Information Platform. As of August 1, 2015, 7,654 CDM projects were registered (the first CDM project was registered in 2004). Table 2 shows the top 10 technology types, host countries, and investing countries in the registered CDM projects. Regarding project types, “wind” ranks first and has 31.8% of the total number of CDM projects while “hydro” ranks second and has 27.0%, which indicates that only two project types comprise 58.8% of the total number of CDM projects. “CERs/year” is equivalent to the expected amount of emissions to be reduced annually on average by specific types of CDM projects. “CERs/year” is not necessarily the same as the volume of CERs actually issued. The shares of wind and hydro in the total volume of CERs/year (992 million tCO_2eq) are 22.8% and 26.6%, respectively. Regarding host countries, 7 out of the top 10 are countries in Asia. In particular, China and India are dominant in the number of projects. China ranks first and shares half of the total number of CDM projects (49.2%) while India shares 20.6%. This indicates that the countries of China and India comprise a combined 69.8% of the total number of CDM projects. China’s share in CERs/year (60.1%) is more than its share in the CDM projects while India’s share in CERs/year (11.4%) is about half of its share in the CDM projects. This suggests that India hosts CDM projects that generate a relatively smaller volume of emissions reduction or emissions absorption compared with China. Regarding investing countries, the UK and Switzerland are dominant in terms of the number of projects while Japan ranks third. The reason why the total number of projects for investing countries (6,441) is smaller than that for project type or host country (7,654) is that the former does not include “unilateral” projects.

Table 2. Top 10 Technology Types, Host Countries, and Investing Countries in CDM Projects

Project type (technology type)	Number	Share (%)	CERs/year (1,000)	Share (%)
1. Wind	2,434	31.8	225,918	22.8
2. Hydro	2,070	27.0	264,148	26.6
3. Biomass energy	646	8.4	44,458	4.5
4. Methane avoidance	638	8.3	25,510	2.6
5. Solar	373	4.9	11,446	1.2
6. Landfill gas	364	4.8	54,293	5.5
7. Energy efficiency (EE) own generation	316	4.1	44,973	4.5
8. N_2O	104	1.4	56,866	5.7
9. Fossil fuel switch	101	1.3	54,001	5.4
10. Energy efficiency (EE) industry	95	1.2	3,617	0.4
Other types	513	6.7	206,831	20.8
Total (27 types)	7,654	100.0	992,061	100.0
Host country	**Number**	**Share (%)**	**CERs/year (1,000)**	**Share (%)**
1. China	3,763	49.2	596,082	60.1
2. India	1,576	20.6	112,840	11.4
3. Brazil	338	4.4	48,425	4.9
4. Vietnam	254	3.3	17,926	1.8
5. Mexico	191	2.5	19,325	1.9
6. Indonesia	147	1.9	17,881	1.8
7. Thailand	146	1.9	7,235	0.7
8. Malaysia	143	1.9	8,405	0.8
9. Chile	102	1.3	11,273	1.1
10. South Korea	91	1.2	20,168	2.0
Other countries	903	11.8	132,501	13.4
Total (114 countries)	7,654	100.0	992,061	100.0
Investing country	***Number**	**Share (%)**	**CERs/year (1,000)**	**Share (%)**
1. UK	2,214	34.4	n.a.	n.a.
2. Switzerland	1,260	19.6	n.a.	n.a.
3. Japan	588	9.1	n.a.	n.a.
4. Netherlands	576	8.9	n.a.	n.a.
5. Sweden	402	6.2	n.a.	n.a.
6. Germany	266	4.1	n.a.	n.a.
7. France	231	3.6	n.a.	n.a.
8. Spain	137	2.1	n.a.	n.a.
9. Italy	99	1.5	n.a.	n.a.
10. Austria	95	1.5	n.a.	n.a.
Other countries	573	8.9	n.a.	n.a.
Total	6,441	100.0	n.a.	n.a.

Data source: Data on project types and host countries are available from "CDM Pipeline spreadsheet" in the UNEP DTU CDM/JI Pipeline Analysis and Database (data are as of August 1, 2015); Data on investing countries are available from the KYOTO Mechanisms Information Platform (data are as of August 31, 2015).

* The total number of CDM projects (6,441) for investing countries does not include "unilateral" projects.

** One unit of CER is equivalent to one metric ton of CO_2 equivalent reduced by the project.

The CDM/JI Pipeline Analysis and Database of UNEP DTU Partnership also includes data on the latest accumulated number of registered JI projects by project type (28 in total) and by host country (19 in total). The data on investing countries of JI projects are available from the KYOTO Mechanisms Information Platform. As of August 1, 2015, 604 JI projects were registered (the first JI project was registered in 2008). There is a fewer number of registered JI projects under investing countries in Table 3 (482 projects) than the numbers under project types and host countries (604 projects) because projects under investing countries are as of August 16, 2014. Table 3 shows the top 10 technology types, host countries and investing countries in JI projects. There are 4 project types in the top 10 JI project types that do not appear in the top CDM project types. They are “fugitive,” “energy distribution,” “coal bed/mine methane” and “energy efficiency (EE) supply side.” Only “fugitive” is dominant in terms of the number of JI projects. “Fugitive” and “EE industry” are dominant in terms of CERs/year. In particular, the dominant share of “fugitive” in CERs/year (46.3%), which is twice as large as its share in the number of projects (21.9%), suggests that this project type generates the largest volume of annual emissions reduction. Regarding host countries, 8 out of 10 host countries in JI projects are economies in transition. Ukraine and Russia are dominant in their shares of the total number of JI projects as well as the total volume of ERUs/year. In particular, Ukraine accounts for 45.7% of the number of JI projects and 58.5% of the volume of ERUs/year while Russia, ranking second, accounts for 16.1% of the number of JI projects and 30.4% of the volume of ERUs/year. Regarding investing countries, the Netherlands and Switzerland are dominant in terms of both the number of projects and the volume of ERUs/year. The Netherlands accounts for 28% of the number of JI projects and 52.3% of the volume of ERUs/year while Switzerland, ranking second, accounts for 21.2% of the number of JI projects and 20.2% of the volume of ERUs/year. The Netherlands’ larger share of the volume of ERUs/year compared with its share of the number of projects suggests that it invests in project types that generate larger emissions reduction.

Table 3. Top 10 Technology Types, Host Countries, and Investing Countries in JI Projects

Project type (technology type)	Number	Share (%)	ERUs/year (1,000)	Share (%)
1. Fugitive	132	21.9	114,720	46.3
2. Energy efficiency (EE) industry	83	13.7	34,347	13.9
3. Landfill gas	67	11.1	1,690	0.7
4. Energy distribution	47	7.8	14,955	6.0
5. N_2O	46	7.6	18,493	7.5
6. Wind	43	7.1	3,036	1.2
7. Biomass energy	38	6.3	2,680	1.1
8. Coal bed/mine methane	28	4.6	9,798	4.0
9. Energy efficiency (EE) supply side	23	3.8	8,829	3.6
10. Hydro	20	3.3	2,453	1.0
Other types	77	12.7	36,984	14.9
Total (28 types)	604	100.0	247,984	100.0
Host country	**Number**	**Share (%)**	**ERUs/year (1,000)**	**Share (%)**
1. Ukraine*	276	45.7	145,099	58.5
2. Russia*	97	16.1	75,277	30.4
3. Czech Republic*	58	9.6	1,255	0.5
4. Poland*	36	6.0	5,138	2.1
5. Bulgaria*	30	5.0	2,956	1.2
6. Romania*	18	3.0	4,745	1.9
7. Lithuania*	18	3.0	2,045	0.8
8. France	17	2.8	2,830	1.1
9. Germany	12	2.0	4,475	1.8
10. Estonia*	12	2.0	424	0.2
Other countries	30	5.0	3,740	1.5
Total (19 countries)	604	100.0	247,984	100.0
Investing country	***Number**	**Share (%)**	**ERUs/year (1,000)**	**Share (%)**
1. Netherlands	135	28.0	n.a.	n.a.
2. Switzerland	102	21.2	n.a.	n.a.
3. Germany	36	7.5	n.a.	n.a.
4. Latvia*	33	6.8	n.a.	n.a.
5. UK	25	5.2	n.a.	n.a.
6. Estonia*	22	4.6	n.a.	n.a.
7. World Bank	19	3.9	n.a.	n.a.
8. Denmark	17	3.5	n.a.	n.a.
9. Japan	16	3.3	n.a.	n.a.
10. Sweden	9	1.9	n.a.	n.a.
Other countries	65	13.5	n.a.	n.a.
Not determined	3	0.6	n.a.	n.a.
Total	482	100.0	n.a.	n.a.

Data source: Data on project types and host countries are available from the "JI Pipeline spreadsheet" in the UNEP DTU CDM/JI Pipeline Analysis and Database (data are as of August 1, 2015). Data on investing countries are available from the KYOTO Mechanisms Information Platform (data are as of August 26, 2014).

*Economies in Transition. There are 13 economies in transition out of 40 Annex I countries.

**One unit of ERU is equivalent to one metric ton of CO_2 equivalent reduced by the project.

4.2. International Emissions Trading

The contribution of IET to ITT is difficult to ascertain since there are not data that can indicate the linkage between the trading of AAUs and technology innovation. Does the trading of credits provide countries or firms with sufficient incentive to allow them to develop technological innovation? If a country or firm can develop innovative climate technologies that would accelerate domestic emissions reduction, they might have a surplus of AAUs, and then, make profits by selling AAUs to other countries or firms. On the other hand, if a country or firm can develop innovative climate technologies, they might not have to buy the AAUs from other countries: instead they can reduce domestic emissions by themselves. This subsection investigates the Annex I countries that are more likely to be engaged in developing innovative climate technologies. Table 4 shows the top 10 sellers (and Japan) and the top 10 buyers in AAU trading. The total volume of trading during 2008 and 2014 was 10,806 million tCO2eq. That is about half of greenhouse gas emissions by Annex I countries in 2012 (20,110 million tCO_2eq). Trading volumes of the other three credits issued under the Kyoto Mechanisms, namely CERs, ERUs and RMUs were respectively 5,387 million t CO_2eq during 2008-2014, 2,901 million tCO2eq during 2009-2014, and 21 million tCO2eq during 20112014, respectively (IGES). Of the top 10 seller countries, 8 (the U.K., France, Denmark, Germany, the Netherlands, Italy, Spain and Switzerland) are also included as top buyer countries. In addition, most of these countries are included in the top ten investing countries of CDM and JI projects (see Tables 2 and 3). However, it is difficult to state that these countries are likely to develop innovative technologies since, as mentioned, there are no data that can indicate the linkage between the trading of AAUs and technology innovation.

Table 4. Trading of AAUs among Annex I Countries (20082014)

Seller			Buyer		
Country	Volume (1,000 AAUs)	%	Country	Volume (1,000 AAUs)	%
1. UK	2,163,755	20.0	1. UK	2,053,219	19.0
2. France	1,967,972	18.2	2. France	1,791,239	16.6
3. Denmark	1,326,157	12.3	3. European Community Registry	1,778,123	16.5
4. Germany	1,305,038	12.1	4. Denmark	1,316,862	12.2
5. Netherlands	769,683	7.1	5. Germany	1,041,221	9.6
6. Italy	426,417	3.9	6. Netherlands	716,646	6.6
7. Czech Republic	336,448	3.1	7. Spain	307,745	2.8
8. Spain	328,089	3.0	8. Italy	290,410	2.7
9. Poland	320,067	3.0	9. Japan	227,714	2.1
10. Switzerland	194,080	1.8	10. Switzerland	205,030	1.9
Japan	660	0.0	Other countries (28 countries)	1,077,758	10.0
Other countries (26 countries)	1,667,604	15.4			
Total	10,805,968	100.0	Total	10,805,968	100.0

Data source: IGES, National Registry Database

5. Survey Results: Review of Literature on the Clean Development Mechanism and Joint Implementation

Existing empirical studies on the contribution of the Kyoto Mechanisms to the international diffusion of climate technologies focus mostly on the CDM while a few focus on both the CDM and JI. The literature search for this study found no empirical study focusing on IET although there are several theoretical studies (e.g., Greaker and Hagem, 2014; Hagem, 2009).

Tables 2 and 3 in Subsection 4.1 show the main project types (technology types), main host countries (technology-receiving countries) and main investing countries (technology-providing countries) in the registered CDM and JI projects, respectively. The tables clarify that European countries benefit from CDM and JI projects since they are dominant providers of the technologies used in CDM and JI projects (Youngman et al., 2007). This suggests that European countries are dominant in the world market of climate technologies. Tables 2 and 3 indicate the main technology types that are most likely to be transferred and the main countries that are most likely to receive or provide technologies through CDM and JI projects, respectively. However, the tables cannot reveal anything about whether ITT actually occurs in CDM and JI projects. Most existing empirical studies focusing on the CDM use the data on technologies described in PDDs, which must be submitted by implementing entities of investing countries to

DOEs for the validation of CDM/JI (Track 2) projects. This includes information on the technologies relating to the project activities such as: “what kinds of technologies are adopted”; “whether those technologies are transferred to host countries”; and “how they are transferred.” This information is publicly available in the CDM/JI Pipeline of the UNEP DTU Partnership. In addition to PDDs, there is other information to ascertain whether ITT occurs via CDM or JI projects, namely, whether the project is “unilateral.” Since unilateral projects are implemented only by host countries without the involvement of investing countries, ITT does not take place in unilateral CDM/JI projects while domestic technology diffusion might occur instead.

Regarding the first research question in this study, “to what extent do the Kyoto Mechanisms contribute to the international diffusion of climate technologies?” Schneider et al. (2008) indicates that there are two main streams in the studies on the contribution of the CDM to ITT. Some studies analyze the relationship between CDM activities and investment flows (e.g., Ellis and Kamel, 2007) while others analyze PDDs of CDM projects (e.g., Dechezleprêtre et al., 2008). As far as the literature search in this study is concerned, however, it seems that most of the literature reviewed uses PDDs. The overall finding of the literature based on the analysis of PDDs is that in half or less than half of the CDM projects, ITTs take place. Using PDDs, Dechezleprêtre et al. (2008) finds that ITTs of (equipment, knowledge, or equipment and knowledge) take place in 43% of 644 CDM projects. Murphy et al. (2015) finds that at least 39% of a data set of 3,949 CDM projects registered as of March 31, 2012, involves ITT. In addition, these two studies investigate the main host and investing countries in ITT by CDM project (technology) type. Table 5 is a summary of the findings in Dechezleprêtre et al. (2008). For example, the main countries of origin of the transferred technologies in CDM projects of “biomass energy” are Belgium, Denmark and Japan while the main countries of destination are Malaysia, India, Brazil and Indonesia. Haites el al. (2006) show similar results to these two studies regarding the frequency of ITT. Based on a data set of 860 CDM projects, they find that ITT occur in one-third of them and that larger projects and those with foreign participants tend to induce technology transfer. Youngman et al. (2007) focus on both the CDM and JI. First, they argue that the type of technology transfer widely varies depending on the project type and that there are two types of technology transfer: technology transfer of equipment (hardware) and technology transfer of information or knowledge (software). Then, they develop three criteria for ITT: the technology originates from outside the host country; the technology is new or improved for the host country; and the knowledge and/or capacity to implement the technology in the project is imported from outside the host country. Although there is no accepted definition of “technology transfer” (Murphy 2015), these three criteria seem to be practical. Youngman et al. (2007) find that 33 of a data set of 53 JI projects (62%) involve ITT while 50% of a data set of 63 CDM projects does. Furthermore, for all of the 33 JI projects involving ITT, the technology originates from the outside the host country, while for 18 projects, the technology is new or improved, and for 15 projects, the knowledge and/or capacity to implement the technology in the project is imported from outside the host country. Schneider et al. (2008), who survey the existing empirical literature and conducted expert interviews to assess the contribution of the CDM to ITT, concludes that CDM is the strongest mechanism for technology transfer under the UNFCCC.

In the existing empirical literatures on the contribution of CDM and JI projects to ITT, one important point seems to be missing in their analysis, namely, “unilateral” projects that exist in both the CDM and JI, as mentioned in Subsection 4.1. Although it is not clear whether unilateral projects are included in the data sets of the abovementioned review studies, the frequency of ITT through CDM or JI projects might be higher if unilateral projects are excluded from the data-sets. Furthermore, even though unilateral projects do not involve ITT, they involve domestic technology transfer because host countries must deploy domestic technologies for the projects. This must induce domestic technology diffusion.

Table 5. Main Host and Investing Countries in Technology Transfer by CDM Technology Type in Dechezlepretre et al. (2008)

Technology type	Main countries of origin (Project investing countries)	Main countries of destination (Project host countries)
Biomass energy	Belgium, Denmark, Japan	Malaysia, India, Brasil, Indonesia
Wind power	Denmark, Gernmany, Spain, US	China, India, Brazil, Mexico
Landfill gas	Italy, UK, France, US, Ireland, Netherlands	Brazil, Mexico, Argentina, Chile, China
Hydroflourocarbon decomposition	France, Germany, Japan	China, India
Hydro-power	France, Germany, UK, Spain	Ecuador, Panama, Honduras, South Korea, Mongolia
Agriculture	Ireland, Canada, UK	Mexico, Brazil, Philippines, Ecuador
Energy efficiency in industry	Japan, Italy, US	India, China, Malaysia
N_2O abatement	Germany, Japan, France	South Korea

Source: Dechezleprêtre et al. (2008)

Regarding the second research question in this study, "what are the main factors that influence the international diffusion of climate technologies under the Kyoto Mechanisms?" most of the abovementioned studies quantitatively analyze the factors (or drivers and barriers) that influence ITT through CDM and JI projects. Econometric analysis conducted by Dechezleprêtre et al. (2008) finds that the "size of CDM projects" and the "number of similar CDM projects in a host country" have the most significant impacts on ITT. Larger projects are likely to have stronger positive impacts on ITT because it is easier for investing countries or firms to find credit buyers for larger projects. On the other hand, such projects are likely to have stronger negative impacts on ITT as the number of similar CDM projects in a host country increases because the repetition of similar projects raises the absorptive capacity of similar technologies by a host country. As a result, a host country's need for similar technologies gradually weakens. Murphy et al. (2015) conduct statistical analysis and find the similar results to Dechezleprêtre et al. (2008). Murphy et al. (2015) indicate that the frequency of ITT has declined over time in China, India and Brazil, which are the top three host countries in terms of the number of CDM projects (refer to Table 2), while it has remained high in other host countries. This implies that similar project types have been implemented through CDM projects in these countries. Furthermore, these two studies indicate that the "technological capacity in host countries" has positive impacts on ITT. Their findings suggest that "technological capacity in host countries" is important for technology transfer really to take place in host countries. Youngman et al. (2007) indicate that, while the CDM and JI promote ITT, they are not sufficient to overcome cost and risk barriers and for widespread deployment of climate technologies.

6. Conclusion

6.1. Summary of findings

The empirical literature reviewed in this study shows that the effects of the CDM and JI on the international diffusion of climate technologies is neither strong nor weak. The descriptive statistics based on PDDs in the literature seem not to be robust for several reasons. First, the literature reports that there are some PDDs without any information on technology. Second, there is no uniform definition of ITT. Therefore, the results on the frequencies of ITT through CDM and JI projects vary depending on the definitions given by the researchers. Third, a part of CDM and JI projects are "unilateral." The recognition of "unilateral" projects is important when considering the effects of the CDM and JI on the international diffusion of climate technologies because such projects do not involve ITT but induce domestic technology transfer or technology innovation. Lastly, since there are many channels for ITT, it is very difficult to single out the effect of the CDM or JI on ITT. On the other hand, the literature shows several factors that influence the frequencies of ITT through CDM and JI projects. First, the frequency of ITT varies by host country and technology type. In particular, the “size of CDM projects,” “size of host countries,” “number of similar CDM projects in a host country,” and “host country’s absorptive capacity of technology” are commonly identified as significant factors. Hosting a large number of projects like in China, India, and Brazil does not necessarily suggest a large frequency of ITT.

6.2. Implications for future research and post-Kyoto frameworks

The findings of this study have several implications for post-Kyoto frameworks to enhance the international diffusion of climate technologies as well as for new paths for future research areas. First, the literature search for this study found no empirical study on the effects of IET on the international diffusion of climate technology. Since the assessment of the overall effects of Kyoto-Mechanisms is crucial for formulating post-Kyoto frameworks, a study that investigates whether IET is effective in incentivizing countries or firms to develop innovative technologies should be an important research area. Second, while IET has been implemented as one of the flexible mechanisms of the Kyoto Protocol, many sub-national ETSs have been introduced across the world, including in Japan, the US, Canada, Australia, India and China (World Bank, 2014, pp.48-75). In the near future, it is likely that those ETSs will be linked to each other. In this sense, it is necessary to examine how to incorporate the issue of international diffusion of climate technology into the design of the scheme for such linked ETSs. Third, unilateral projects could be an effective channel for domestic technology transfer and, thus, technology diffusion in developing countries. Fourth, the literature reviewed suggests the importance of the absorptive capacity of technology in ITT. Lastly, existing empirical literature indicate that larger CDM projects have positive impacts on the frequencies of ITT. This takes place because such projects are likely to be acknowledged by the CDM executive board and because project developers easily find buyers of CER credits, which makes it possible to invest in the projects. On the other hand, smaller CDM projects take longer time to be acknowledged, which gives developers less incentives to invest in the project. This suggests that speedier acknowledgement procedures are necessary to give developers more incentives to participate in CDM projects. To remedy this shortcoming in the CDM, the Joint

Crediting Mechanism (JCM) was proposed by the Japanese Government (World Bank, 2014, p.121). Recently, the Japanese Government has initiated JCM projects to transfer climate technologies developed by Japanese municipalities, for example, smart-city technologies. This is unique in the sense that the projects aim to transfer relevant technologies owned by Japanese municipalities as a package to municipalities in other Asian countries.

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