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Factors driving international technology transfer: empirical insights from a CDM project survey

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This study empirically explores factors driving international technology transfer via Clean Development Mechanism (CDM) projects by explicitly considering factors that have been identified in the literature on international technology transfer as being relevant for transfer success. These factors include technological characteristics, such as the novelty and complexity of a technology, as well as the use of different transfer channels. Employing data from an original survey of CDM project participants, the econometric analysis also distinguishes between knowledge and equipment transfer. The findings suggest that more complex technologies and the use of export as a transfer channel are both associated with a higher degree of technology transfer. Projects involving two- to five-year-old technologies seem more likely to involve technology transfer than both younger and older technologies. Energy supply and efficiency projects are correlated with a higher degree of technology transfer than non-energy projects. Unlike previous studies, technology transfer was not related to project size, to the length of time a country has hosted CDM projects, or to the host country's absorptive capacity. The findings for knowledge and equipment transfer are similar, but not identical.

Policy relevance

CDM projects are often seen as a vehicle for the transfer of climate technologies from industrialized to developing countries. Technology transfer is an important element of the new and emerging market mechanisms and frameworks under the United Nations Framework Convention on Climate Change, such as the Technology Mechanism, Nationally Appropriate Mitigation Actions, or Intended Nationally Determined Contributions. Thus, a clearer understanding of the factors driving technology transfer may help policy makers in their design of such mechanisms. For the CDM, this may be achieved by including more stringent technology transfer requirements in countries' CDM project approval processes. Based on our findings, such policies should focus particularly on energy supply and efficiency technologies. Likewise, it may be beneficial for host countries to condition project approval on the novelty and complexity of technologies and adjust these provisions over time. Since such technological characteristics are not captured systematically by project design documents, using a survey-based evaluation opens up new opportunities for a more holistic and targeted evaluation of technology transfer in CDM projects.

Keywords: Clean Development Mechanism; development and climate; energy technology; North–South; technology transfer

1. Introduction

When the United Nations Framework Convention on Climate Change (UNFCCC) was established in 1992, non-Organisation for Economic Co-operation and Development (OECD) countries accounted

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for 44% of global energy-related CO_2 emissions (IEA/OECD, 2014), and subsequent UN climate policy, notably the Kyoto Protocol, required most developed countries to limit their GHG emissions, while developing countries did not face such targets. The share of CO_2 emissions by non-OECD countries has since increased (to 61.7% in 2012), and is projected to reach 72.7% by 2035 (IEA/OECD, 2014).

Enhancing developing countries' access to climate technologies is therefore an important contribution to effectively addressing climate change at the global level. To this end, Article 4.5 of the UNFCCC prescribes that '[t]he developed country Parties [...] shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties....' (UNFCCC, 1992).

In particular, the Clean Development Mechanism (CDM) allows developed (Annex I) countries to meet their national emissions targets using emissions reductions achieved through projects in developing countries. While not one of its explicit goals, the CDM is frequently perceived as a vehicle for international technology transfer (TT) (Dechezleprêtre, Glachant, & Ménière, 2008, 2009; Murphy, Kirkman, Seres, & Haites, 2015; Popp, 2011; Schneider, Holzer, & Hoffmann, 2008; Weitzel, Liu, & Vaona, 2014). As part of the CDM approval process, host countries may require these projects to involve TT (UNFCCC, 2010), but only few countries have done so explicitly (Spalding-Fecher et al., 2012).

Previous studies have empirically explored to what extent the CDM contributes to international TT, but findings differ to some degree. According to Murphy et al. (2015), about 40% of registered CDM projects involve TT. Haites, Duan, and Seres (2006) and Seres, Haites, and Murphy (2009) report that about one-third of CDM projects, accounting for about 60% of the CDM's annual emissions reductions, involve TT. Das (2011), on the other hand, concludes that the 'contribution of the CDM to technology transfer can at best be regarded as minimal' (Das, 2011, p. 28).

Several studies have also employed econometric analyses to explore the factors driving TT through the CDM (e.g. Dechezleprêtre et al., 2008, 2009; Haites et al., 2006; Haščič & Johnstone, 2011; Schmid, 2012; Weitzel et al., 2014). These factors typically include project size, technology sector, length of a host country's experience with the CDM, and its technological capabilities. The extant literature largely draws on information available directly from the project design documents (PDDs) of CDM projects, which is regularly gathered by the UNEP DTU and published in its CDM Pipeline (Fenhann, 2014), as well as from the supplementary dataset provided by UNFCCC (2010).

In this study we analyse the factors driving international TT via CDM projects. Our analysis extends previous work by explicitly considering factors that have been identified in the general literature on international TT as being relevant for transfer success (Davidson & McFetridge, 1984, 1985; Hakanson, 2000; Stock & Tatikonda, 2000; Tsang, 1997). In particular, we explore how technological characteristics (technological complexity and novelty) and the type of transfer channel used relate to TT. Our analysis relies on new and original data collected through a survey among participants in CDM projects. This survey-based approach allows for a more nuanced evaluation of the degree of TT as compared to the assessment in UNFCCC (2010), which provides a binary indicator of whether TT is expected or not. Finally, because the survey data were gathered at a later stage of project implementation than the data in UNFCCC (2010), we rely on an updated assessment about the extent of TT involved.

The article is organized as follows. Section 2 specifies the theoretical background and derives our research hypotheses. Section 3 describes the data, methodology, and econometric models employed. Section 4 presents the results. Section 5 discusses the main findings and concludes.

2. Background

Despite the prevalence of TT in academic and policy analyses, there is no universally accepted definition (Popp, 2008). Following the Intergovernmental Panel on Climate Change (IPCC), TT may be understood as

> a broad set of processes covering the flows of knowledge, experience and equipment ... amongst different stakeholders ... The broad and inclusive term 'transfer' encompasses diffusion of technologies and technology cooperation across and within countries ... It comprises the process of learning to understand, utilise and replicate the technology, including the capacity to choose it and adapt it to local conditions. (Metz, Davidson, Martens, van Rooijen, & Van Wie McGrory, 2000, p. 3)

Several studies have explored factors driving TT in the CDM. Dechezleprêtre et al. (2008), Haites et al. (2006), Schmid (2012), and Seres et al. (2009) find that larger projects are more likely to involve TT, because TT costs are fixed and represent an impediment to smaller projects (Dechezleprêtre et al., 2008). Most studies also control for technology type or sector. The findings by Haites et al. (2006), Seres et al. (2009) and Weitzel et al. (2014) suggest that the likelihood of TT is higher for wind power projects and lower for hydro power projects (see also Murphy et al., 2015). Several studies also account for the impact of host country characteristics. In particular, Weitzel et al. (2014), for projects in China, and Murphy et al. (2015), for projects in Brazil, China, and India, find TT to be lower the longer a country has had experience with the CDM.

In these studies, TT enters the analysis as a binary dependent variable, typically relying on the nominal codes used in UNFCCC (2010), which are based on a keyword search for 'technology' in each PDD. TT is then categorized based on eight different codes, indicating whether TT was mentioned, whether it is expected, and, if so, its type (equipment, knowledge, and/or joint venture). Thus, while the coding is detailed, UNFCCC (2010) does not differentiate between degrees of TT. Dechezleprêtre et al. (2008), among others, suggest that PDD editors might overstate the amount of expected TT. However, using a follow-up survey, Murphy et al. (2015) find that PDDs instead demonstrate a tendency to underestimate TT. Moreover, because of the limited information provided by PDDs, some of the factors that have been highlighted in the literature on international TT have not been adequately included in previous CDM studies. In particular, TT can involve the transfer of tacit knowledge (Kogut & Zander, 1993). Tacit knowledge means that people know more than they can explain (Polanyi, 1966), which has implications for the transfer of knowledge. Whereas explicit knowledge can be codified and transferred, tacit knowledge is difficult to codify and is closely tied to individuals that possess it. Applying existing knowledge to new uses frequently requires a transfer of this knowledge within or across organizational boundaries.

Building on earlier research, Tsang (1997) states that the relevance of tacit knowledge depends on the age and complexity of the technology. Mature technologies have been widely used in the industry and consequently much of the previously tacit knowledge has been codified (Dosi, Teece, & Winter, 1992; Teece, 1977). On the other hand, because cutting-edge technology is still subject to frequent changes, the associated knowledge is difficult to codify. However, a high degree of complexity can hamper attempts to codify the underlying knowledge, even for mature technologies (Tsang, 1997).

Existing research on CDM projects has paid only minor attention to these technological characteristics, and the limited empirical evidence has been inconclusive regarding their impact on transfer success. Byrne, Smith, Watson, and Ockwell (2012) suggest that the maturity of the technology is crucial for the successful transfer of technologies to developing countries. However, Murphy et al. (2015) state that the least amount of TT takes place in CDM projects involving 'widely available, mature technologies' (Murphy et al., 2015, p. 133), while empirical findings from Dechezleprêtre et al. (2008) suggest that CDM projects in the energy sector and chemicals industry contribute more to TT than projects in agriculture, because the former involve more complex technologies. We therefore formulate the following hypotheses:

H1: The more complex the technology employed in the project, the higher is the technology transfer.

H2: The newer the technology employed in the project, the higher is the technology transfer.

Moreover, the presence of tacit knowledge components in the technology to be transferred may influence the choice of transfer channel (Hakanson, 2000; Kogut & Zander, 1993). Tsang (1997) argues that the tacit components of technological knowledge need to be transferred through close human interactions, such as in joint ventures or wholly owned subsidiaries. Stock and Tatikonda (2000) try to match the degree of uncertainty associated with the technology and the degree of organizational interaction between technology source and recipient. Similar to Tsang (1997), they argue that high technological uncertainty should coincide with a high degree of organizational interaction. Empirical findings indicate that firms prefer Foreign Direct Investment (FDI) to transfer newer technologies and licensing to transfer older technologies, which can be explained by the need to protect valuable knowledge from imitation by local competitors.[1] Dechezleprêtre et al. (2008) highlight the relevance of transfer channels for TT in CDM projects, finding that the probability that a project contributes to TT is 50 percentage points higher when it is developed in a subsidiary of a company from an Annex I country. Our empirical analysis distinguishes between the following four transfer channels: export and licensing, which are market-based and exhibit a low degree of organizational interaction, and joint ventures and wholly owned subsidiaries, which are characterized by closer interactions due to their hierarchical coordination. Based on these considerations, we posit the following:

H3: The channels 'jointventure' and 'subsidiary' will be associated with higher technology transfer than 'export' and 'licensing'.

Finally, the transfer of tacit knowledge also depends on the recipient countries' ability to absorb new technologies. World Bank (2008) describes absorptive capacity as including 'governance and the business climate', 'basic technological literacy', 'finance of innovative firms', and 'proactive policies'. Many studies on TT in the CDM use a narrower definition of absorptive capacity focusing on technological capabilities, due to the lack of available data for non-OECD countries. For example, Haščič and Johnstone (2011) use patent data and found a positive effect on the transfer of wind power technology. Dechezleprêtre et al. (2008) use the ArCo technology index (Archibugi & Coco, 2004) and find the impact of sector-specific technological capabilities on TT in CDM projects conditional on their level: a certain level of ability is necessary for the absorption of new technologies. However, with increasing abilities and availability of local technologies, the contribution of CDM projects to TT decreases. Supporting these findings, Doranova, Costa and Duysters (2010) conclude that, given a strong knowledge base in the recipient countries, CDM projects tend to use local or a combination of local and foreign technologies, instead of foreign technologies only. In comparison, Schmid (2012) found no statistically significant relation between TT and tertiary education or research and development (R&D) indicators. Assuming a definition of absorptive capacity that is closer to the World Bank interpretation, our final hypothesis is as follows:

H4: The higher the absorptive capacity of the host country, the higher is the technology transfer involved.

3. Data and methodology

3.1. Survey

Empirical data were collected via an online survey of participants from CDM projects. Contact information for participants from 4313 projects was gathered from the PDDs of the 4984 CDM projects listed in the UNFCCC's CDM database on 30 June 2010 (UNFCCC 2010). At that time, 2425 projects were at validation, 2389 had been registered, and 170 projects were being considered for registration.

The online survey was conducted between 22 August 2013 and 29 September 2013 and resulted in 137 responses (see Appendix 1). About one-third of respondents were consultants (35%)[2], 28% came from small and medium enterprises, and 10% represented transnational corporations. Moreover, 66% of participants were on the receiving side of TT (technology recipient or supporting party) and 31% represented technology suppliers.

The sample of projects that entered into the econometric analysis is not representative for the population of CDM projects. In the CDM database, the share of projects from Asia is higher (78.9% vs. 61.4% in our sample) and the shares of projects in Africa (2.6% vs. 11.4%) and South America (13.8% vs. 24.3%) are lower than in our sample.[3] The survey was conducted in English, which may have resulted in a language barrier for some participants (for this reason, we chose not to include the complex IPCC definition of TT in the survey). This barrier may also explain the low representation of Asian countries in the sample, particularly China.

To assess TT in CDM projects, respondents were asked to what extent 'equipment and technical components'/'knowledge and experience' were transferred to the receiving parties for the technology in question.[4] As can be seen in Figure 1, about two-thirds of the respondents thought that a medium to very high extent of knowledge transfer (KT) and equipment transfer (ET) had taken place in their project. Nevertheless, 23% (equipment) and 16% (knowledge) of participants stated that their project did not involve any TT. We also compared the survey-based assessments of TT with the corresponding PDD-based assessments of the same project provided in the

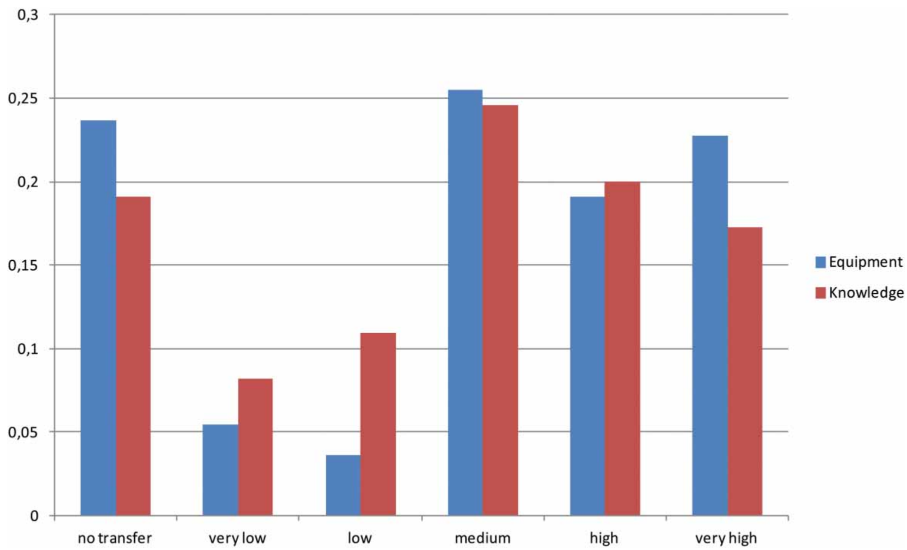

FIGURE 1 Assessment of the degree of technology transfer to receiving parties in the project ($N = 110$)

UNFCCC study. For 9% of the projects in our sample, the survey-based assessment of ET is lower than the PDD-based transfer. For 27% of projects, the survey-based assessment of ET is higher than the PDD-based assessment. Similarly, for 12% of the projects, the survey-based assessment of KT is lower and for 32% it is higher than the PDD-based assessment.[5] This leads to the conclusion that TT tends to be underestimated in PDDs.

One reason for the relatively high share of stated TT in our sample might be a selection bias toward projects with TT. Projects with no or low TT may have decided to abstain because they felt that they could not contribute. In this case, the TT incorporated in the projects in our sample would be higher than in the population of all CDM projects. Our econometric analysis would produce biased parameter estimates if there was some unmeasured factor driving participation in the survey that is also correlated with an explanatory variable. *A priori* it is not clear, though, what these unmeasured factors or the direction of the bias might be in the given context. Moreover, parameter estimates would not be biased if the outcome equation included all factors driving survey participation. Logically, this assumption cannot be tested, but our econometric model allows for a rather broad set of explanatory variables.

3.2. Econometric model

Econometric analysis is used to empirically assess the relationship between KT/ET and a set of explanatory variables based on our survey, including information on technology complexity, novelty, and choice of transfer channel. The explanatory variables also include variables that have typically been employed in the literature, such as project size, sector dummies, time dummies, and absorptive capacity.

3.2.1. Dependent variables

The dependent variables used are *knowledge* transfer and *equipment* transfer, which we assume to be influenced by the characteristics of the technology, the choice of transfer channel, and the host countries' absorptive capacity. To narrow down the scope of our analysis, we examine only KT pertaining to the production, replication, adaptation, and usage of equipment, which excludes knowledge that is transferred in the form of services. In the context of our survey, *knowledge* stands for respondents' perception of the technological knowledge and experience that was transferred to the receiving parties of the CDM project. Similarly, *equipment* reflects the extent to which equipment and technical components were transferred. For both variables, responses are coded from 0 ('no transfer') to 5 ('very high transfer').

3.2.2. Explanatory variables

Because knowledge tacitness is difficult to capture empirically, we use technological complexity and novelty as proxies. In the survey, respondents were asked to assess the complexity of the technologies employed in their project. The original answers were scaled from 1 ('very low complexity') to 5 ('very high complexity'). The responses were used to create *complexity*, a binary variable, which takes on the value of 1 if respondents answered 'very high complexity' and 0 otherwise.[6]

Similarly, the questionnaire asked respondents to assess the novelty of technologies. They were asked how old the version, type, or model of the technology utilized in the project was at the time that the project started. The five answer categories were 0–2 years, 3–5 years, 6–10 years, 11–15 years, and >15 years. To save degrees of freedom but allow for nonlinearity in the marginal effects, we created three dummy variables, *novelty1* ('0–2 years'), *novelty2* ('3–5 years'), and *novelty3* ('>5 years').

We further differentiate between four transfer channels: *export*, *licensing*, *jointventures*, and *affiliated* companies or subsidiaries. Respondents were asked to what extent these channels were used for transferring technical equipment and/or knowledge to the recipient parties. The response categories ranged from 1 ('very low') to 5 ('very high'). Rather than including dummy variables for each response category, we collapse categories 1 to 4 and create a binary variable, *complexity*, to be included in the analysis, thereby saving degrees of freedom. The dummy variables *export*, *licensing*, *jointventure*, and *affiliated* take on the value of 1 if the transfer channel is used to a 'high' or 'very high' degree, and 0 if it is used to a 'very low', 'low', or 'medium' degree.

To capture differences in countries' abilities to incorporate new knowledge and technologies, a variable reflecting countries' absorptive capacity was used. We gathered country data for 2012–2013 from the World Economic Forum's (WEF) Global Competitiveness Report (Schwab & Sala-i-Martin, 2013) to construct the variable *absorptivecap*. The following five indicators were used from the WEF database: public institutions, infrastructure, higher education and training, technological readiness, and innovation. For each indicator, countries are ranked on a scale between 1 and 7. An exploratory factor analysis showed that these five items all loaded on a single factor. After checking reliability (Cronbach's $\alpha = 0.91$), *absorptivecap* was calculated as the average ranking of the five indicators.

To control for a possible decrease in the amount of TT over time, *CDM_age* is calculated on a country level as the difference between the year each project was registered and the year in which the first CDM project was registered in that country.[7] Following the literature, we use the amount of expected GHG emissions savings (i.e. Certified Emission Reductions, CERs) of a project per year (in tCO_2/yr) as an indicator for project size and employ its natural log in the actual implementation (*lnsize*). Finally, to capture sector effects, we include *energy* to reflect whether a project involves energy supply or energy efficiency technologies. Apart from energy supply projects like wind or hydro power, energy also includes projects labelled as 'landfill gas', 'methane recovery' (based on references to energy production in the project title), 'fuel switch', and energy efficiency projects in industry and residential sectors.[8]

TABLE 1 Descriptive statistics ($N = 70$)

Variable		Mean	Std. dev.	Min.	Max.
knowledge[a]	Ordinal variable of perceived knowledge transfer				
	0 (no)	0.13			
	1 (very low)	0.09			
	2 (low)	0.10			
	3 (medium)	0.29			
	4 (high)	0.19			
	5 (very high)	0.21			
equipment[a]	Ordinal variable of perceived equipment transfer				
	0 (no)	0.17			
	1 (very low)	0.06			
	2 (low)	0.03			
	3 (medium)	0.29			
	4 (high)	0.20			
	5 (very high)	0.26			
complexity	Dummy for technology associated with 'very high complexity'	0.07	0.26	0	1
novelty1	Dummy if technology is 0 to 2 years old	0.39	0.49	0	1
novelty2	Dummy if technology is 3 to 5 years old	0.21	0.41	0	1
novelty3	Dummy if technology is older than 5 years	0.40	0.49	0	1
export	Dummy if export is used to a 'high', or 'very high' degree as a transfer channel	0.46	0.50	0	1
licensing	Dummy if licensing is used to a 'high', or 'very high' degree as a transfer channel	0.17	0.38	0	1
jointventure	Dummy if a joint venture is used to a 'high', or 'very high' degree as a transfer channel	0.23	0.42	0	1
affiliated	Dummy if an affiliated company/subsidiary is used to a 'high', or 'very high' degree as a transfer channel	0.23	0.42	0	1
absorptivecap	Average country ranking for five indicators of absorptive capacity	3.83	0.53	2.89	5.99
CDM_age	Difference between project registration year and year of first CDM project registration in host country	4.46	2.48	0	11
lnsize	Logarithm of expected CERs in tons per year	10.88	1.48	7.85	13.86
energy	Dummy for energy supply or energy efficiency projects	0.64	0.48	0	1

[a]Shares of outcomes are reported

Table 1 provides descriptive statistics of the dependent and explanatory variables.[9] As *knowledge* and *equipment* are ordinal, we report their shares. For example, 21% of the respondents reported KT to be 'very high', and 26% of the respondents reported ET to be 'very high'.

3.2.3. Econometric model

Because the dependent variables are ordinal, we estimate ordered response models, specifically ordered logit models.[10]

4. Results

We use STATA13 to run the ordered logit models for *knowledge* and *equipment*.[11] To prevent singularity of the regressor matrix, *novelty1* is not included in the set of explanatory variables. Thus, *novelty1* serves as the base for *novelty2* and *novelty3*. Results for both equations are shown in Table 2.

The Wald test statistics on the combined statistical significance of all parameters imply that the null hypothesis that all parameters of the explanatory variables are zero can be rejected at $p < 0.01$ for both equations.[12]

The findings suggest that KT and ET both increase with rising *complexity*. That is, for technologies that are perceived to be very complex, KT/ET is higher than for technologies perceived to be less complex. For technologies that were older than five years at the time the project started (*novelty3*), KT/ETs are found to be lower than for technologies that had been on the market for less than two years, while our results suggest that technologies that are between three and five years old are associated with higher KT than the newest technologies (0–2 years). Using export or – in more general terms – arm's length market transfer as a channel for TT in CDM projects is associated with a higher KT/ET than projects that do not use export. Apart from *export*, no other transfer channel was found to be statistically significant.

The parameter estimates associated with the variables reflecting a host country's absorptive capacity (*absorptivecap*), the length of time it has hosted CDM projects (*CDM_age*), and the size of the project (*lnsize*) are not statistically significant in either equation. Finally, energy supply and energy efficiency projects are positively correlated with KT/ET, but the *p*-value of *energy* in the equipment equation ($p =$ 0.311) is above the conventional levels of significance.

4.1. Marginal effects

Similar to binary response models such as logit or probit models, in ordered response models, the coefficients reported in Table 2 cannot be interpreted as estimators of the effect of a marginal change in the explanatory variable on the dependent variable, i.e. the probability of observing a particular outcome. In addition, the coefficients do not generally indicate the direction of the estimator of these marginal (probability) effects. To provide additional insights and allow for further interpretation of the econometric findings, Tables 3 and 4 display the average marginal probability effects of *complexity* and *export* for all categories, ranging from 0 ('no transfer') to 5 ('very high transfer'), of *knowledge* and *equipment*.

For example, using a technology that is considered highly complex as opposed to not highly complex decreases the probability of involving 'low' KT (i.e. category 1) by 7 percentage points, and

TABLE 2 Results of ordered response models

	knowledge	*equipment*
complexity	1.579**	3.485***
	(0.716)	(1.103)
novelty2	1.297**	0.296
	(0.630)	(0.693)
novelty3	− 1.121*	− 1.201*
	(0.577)	(0.626)
export	1.732***	2.415***
	(0.528)	(0.656)
licensing	0.569	0.738
	(0.885)	(0.802)
jointventure	− 0.852	− 1.072
	(0.983)	(0.811)
affiliated	1.037	0.246
	(1.040)	(0.882)
absorptivecap	0.0426	− 0.235
	(0.508)	(0.482)
CDM_age	0.0241	0.0819
	(0.0852)	(0.0925)
lnsize	0.0693	0.0734
	(0.191)	(0.198)
energy	1.440**	0.803
	(0.719)	(0.793)
Sample size	70	70
Wald χ^2	37.07***	40.65***
Pseudo R^2 (McFadden)	0.1423	0.1843

Notes: Robust standard errors appear in parentheses.
*Significance at $p < 0.1$ in an individual two-tailed t-test. **Significance at $p < 0.05$.
***Significance at $p < 0.01$.

increases the probability of involving ‘very high’ KT (i.e. category 5) by 20 percentage points. Similarly, using technologies that are considered highly complex as opposed to not highly complex decreases the probability of involving ‘low’ ET by 6 percentage points, and increases the probability of involving ‘very high’ KT by 31 percentage points.

Likewise, employing export as a transfer channel decreases the probability of ‘low’ KT by 6 percentage points, and increases the probability of ‘very high’ ET by about 19 percentage points. Similarly, employing export as a transfer channel decreases the probability of ‘low’ ET by 9 percentage points, and increases the probability of ‘very high’ KT by about 44 percentage points.

TABLE 3 Average marginal effect of *complexity* and *export* on *knowledge*

Category	*complexity*	*export*
0	− 0.16	− 0.27
1	− 0.07	− 0.06
2	− 0.05	− 0.05
3	− 0.01	− 0.01
4	0.09	0.08
5	0.20	0.19

TABLE 4 Average marginal effect of *complexity* and *export* on *equipment*

Category	*complexity*	*export*
0	− 0.15	− 0.39
1	− 0.06	− 0.09
2&3	− 0.05	− 0.07
4	0.08	0.12
5	0.31	0.44

4.2. Robustness checks

To assess the robustness of the results presented in Table 2, we conducted several additional estimations involving alternative model specifications.[13]

First, and similar to Dechezleprêtre et al. (2008), Schmid (2012), and Weitzel et al. (2014), we used the number of registered CDM projects carried out in a country for a particular sector prior to the registration date of each project rather than *CDM_age* to reflect a country's experience with a technology. All other variables were kept the same. The parameters associated with the stock of past CDM projects were positive, but not statistically significant ($p > 0.8$ in both equations). Otherwise, the results for this model were virtually identical to those reported in Table 2. The specification including *CDM_age* performs marginally better in terms of the Baysian and Akaike Information Criterions, or the Pseudo R^2.

We further used a specification where complexity included responses with 'high complexity' in addition to 'very high complexity', thereby increasing the number of observations where complexity equals 1 from 5 to 22. In this case, complexity is found to be statistically significant for equipment, but not for KT. The findings for all other coefficients remain virtually unchanged.

Respondents' assessments of TT and complexity may depend on their experience. For example, a project developer with high technological capability may evaluate a technology 'low complexity', while a technologically less experienced project developer may evaluate the same technology 'high complexity'. To control for this type of potential subjectivity, we added a proxy for the responding organization's experience to the set of explanatory variables, i.e. the log of the number of CDM projects the organization had carried out in the past with the partners involved in the current project. The associated coefficient is positive in the *knowledge* equation and negative in the *equipment* equation, but not statistically significant for either ($p < 0.7$ for *knowledge*; $p < 0.3$ for *equipment*). All other results are very close to those in Table 2. Thus, given the data and variables at hand, we have no indication that respondents' characteristics are systematically related to *knowledge*, *equipment*, or *complexity*. Finally, we estimated a model without the explanatory variables from our survey to allow for comparisons with analyses based primarily on explanatory variables taken from the PDD, i.e. *absorptivecap*, *CDM_age*, *lnsize*, and *energy*. None of the coefficients in this model turned out to be statistically significant, and the explanatory power was very weak. In addition, we ran regressions including selected regional dummies (e.g. for China), but the results did not provide any additional insights.

In summary, the results presented in Table 2 appear to be quite robust to alternative model specifications.

5. Discussion and conclusions

Our econometric analysis of the original survey data from the CDM projects implies that more complex technologies are related to a higher transfer of knowledge and equipment than less complex technologies, thus generally corroborating H1.

Our findings for knowledge transfer (but not for equipment transfer) suggest that two- to five-year-old technologies are associated with higher TT than technologies that are either newer than two years or older than five years at the time the project started. There is also weak evidence that technologies that were younger than two years are associated with higher KT and ET than those that were older than five years. Thus, our findings partly support H2; i.e. the newer the technology in the project, the higher the TT involved.

As *complexity* and *novelty* were used as proxies for the degree of tacit knowledge contained in a technology, the results suggest that the transfer of tacit knowledge contributes to the success of TT in the CDM. Less complex technologies may have already been transferred to the host countries in the past and are thus not perceived to contribute much to TT. This finding is generally consistent with Murphy et al. (2015, p. 133), who conclude that CDM projects involving 'widely available, mature technologies' are associated with little TT. Therefore, countries that host a large number of CDM projects, such as China, India, and Brazil, could encourage an increase in TT via CDM projects by mandating technology standards (e.g. in the project approval process) that dynamically adapt to progress in their technological capabilities and to advances at the technological frontier.[14]

Our findings on transfer channels imply that choosing *export* is related to higher knowledge and equipment transfer. No other channel was found to be related to TT. Our findings therefore provide no support for H3. The finding for *export* is not consistent with the literature, which suggests that transfer channels that are characterized by a low degree of organizational interaction contribute less to TT, because they do not allow for interpersonal exchanges of tacit knowledge between technology suppliers and recipients. One explanation for this finding might be that this literature does not account for the specificities of TT in the CDM; given the institutional structure of the CDM, the incentives for technology suppliers from Annex I countries to engage in more intensive forms of organizational interaction, such as joint ventures or FDI, seem to be quite low, because CDM projects are limited in time and geared to emissions reductions rather than market entry. Therefore, export or market transactions, as a form of temporary, one-time interaction between technology supplier and recipient, seem to have a better institutional fit with the CDM than other transfer channels. Another specificity of TT within the CDM is that most CDM projects are closely accompanied by international CDM consultants, with whom there is a high degree of personal interaction and who, in the process of their consultation, may provide some of the necessary tacit knowledge that would otherwise have to be provided by the technology supplier. Thus, the involvement of CDM consultants might partly compensate for the low degree of organizational interaction between technology suppliers and recipients that generally characterizes market-based transactions and explain why exports are associated with a high degree of technology transfer in the CDM.

Similar to Schmid (2012), our results fail to exhibit a statistically significant relationship between TT and the absorptive capacity of the CDM host country. Thus we find no support in favour of H4. Arguably, the country-level indicators that were chosen to construct the variable *absorptivecap* may have been too coarse to predict the extent of KT/ET at the project/firm level. The lack of significance, however, may also result from two countervailing effects that were previously described by Dechezleprêtre et al. (2008). On the one hand, TT requires some minimum level of absorptive capability, implying a positive correlation of absorptive capacity and TT. On the other hand, high absorptive capacity reflects that technologies are already available in a country, implying a negative correlation of absorptive capacity and TT.

Unlike in most previous analyses, project size and the age of the CDM in a country were not statistically significant in our survey-based analysis. This may be due to the relatively small and non-representative sample size or systematic differences in the assessment of TT. Likewise, the additional regressors included in our analysis may explain some of the variation in TT that is otherwise (erroneously) attributed to project size or the age of the CDM. Consistent with the findings by Dechezleprêtre et al. (2008), we find that energy supply and energy efficiency projects are associated with higher KT (but not ET).

Our analysis also distinguishes between two types of TT. The sign of all coefficients is the same for KT and ET, and the significance levels are also quite similar. The findings suggest, however, that projects that involve highly complex technologies or that employ export as transfer channels increase the probability of involving very high TT more for equipment than for knowledge.

The descriptive statistics of our sample data suggest that about two-thirds of the CDM projects involve a medium to very high extent of TT. Similar to Murphy et al. (2015), we find that respondents tend to perceive the TT to be higher than they had originally stated in their PDDs. Hence, for the projects included in our survey, we do not find support for the notion that editors of PDDs overstate the TT of the project. The differences in the assessment of TT between our survey and the PDD-based UNFCCC study (2010) may be due to information updates, because the survey was conducted after the PDD had been submitted. Similarly, the differences may be due to a more direct focus on the issue of TT and/or a more nuanced scale in the survey.

Although our survey-based analysis of the factors driving TT in CDM projects provides additional insights compared to the extant literature, ideally, a large and representative study should corroborate our findings such as those on the relationship between TT and the level of complexity of projects. This could also allow for a more detailed consideration of differences between technologies and countries, and more adequately capture absorptive capacity at the firm level. Likewise, a more in-depth analysis of specific characteristics could employ indicators of the technology-specific capability of countries or firms over time to gain a better understanding of TT and absorptive capacity. Depending on data availability, instrument variable techniques could be used to address the potential endogeneity of transfer channel choice. Complementary to large sample analyses, in-depth interviews could explore the function of international CDM project consultants as knowledge brokers or on measures to foster TT via adequate provisions in the approval process. In this sense, future research could also more adequately recognize that technology transfer is a prolonged process over a period of time, involving cross-exchange of exercise, know-how, organizational capacities, technology design specifications, supervision, etc. Thus, our outcome variables on TT did not adequately reflect the complex and multidimensional nature of technologies, including learning, technological capabilities, and the institutional embeddedness of technology (e.g. Lall, 1992).

Our findings have been derived from CDM projects, yet the CDM market suffers from declining prices for CERs and volumes reflecting lack of political commitment. For example, current legislation on the EU Emissions Trading System will not allow international credits after 2010. While the CDM is likely to fade out, our findings on the factors driving TT are also relevant for new and emerging market mechanisms and frameworks under the UNFCCC, e.g. the Technology Mechanism. Nationally Appropriate Mitigation Actions (NAMAs) by developing countries may also involve support for TT from developed countries under UNFCCC agreements. Similarly, developing countries' Intended Nationally Determined Contributions, which form the basis of global emissions reduction commitments after 2020, may include actions that are conditional on TT through international cooperation (e.g. Mexico). Finally, Japan has initiated the Joint Crediting Mechanism to allow countries that are not participating in the second commitment period of the Kyoto Protocol to engage in a bilateral offset credit mechanism with developing countries, similar to the CDM.

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Notes

1. See Popp (2011) for further references.
2. CDM projects go through a complex project cycle involving project design, validation, registration, implementation, monitoring, verification, certification, and the issuance of emission reduction units (Michaelowa, 2005; Olsen, 2010). Specialized CDM consultants play a key role in this project cycle.
3. For a more detailed comparison of our sample to all CDM projects, see Appendix 2.

4. It should be noted that this pragmatic distinction between equipment and knowledge transfer does not fully account for the complexity of TT. Similarly, while preferable to binary variables, our ordinal outcome variables may still not adequately capture the incremental process of TT (see e.g. Bell, 2012).
5. To compare our survey data with the codes from the UNFCCC study we created a variable *CDM_TT* from the study data that equals 0 if the PDDs indicate no TT or make no mention of transfer, 1 if ET was expected, 2 if KT was expected and 3 for an expectation of both transfer types. We compared this variable with the survey-based assessments. If *CDM_TT* = 1, 2, or 3 and the survey response was 0 or 1 (no or very low transfer) for the respective category, we concluded that TT had been overestimated in the PDD. If CDM_TT = 0 and the survey response for either KT or ET was between 2 and 5 (low to very high transfer), transfer was assumed to have been underestimated.
6. To save degrees of freedom, we do not include dummies for all five response categories as explanatory variables. The final specification of complexity was chosen based on Wald tests, which imply that there is no difference between the parameter values of the four lowest response categories for complexity. Also note that based on these tests, treating the original responses as a continuous variable would not be correct. We also note that reducing technology complexity to a scale with two (or five outcomes) may be an oversimplification of the multi-dimensional nature of technologies.
7. For the nine projects in our sample where the project status was 'at validation' or 'replaced at validation', we assumed 2015 as the year of registration.
8. To save degrees of freedom and because other sectors did not contain sufficient observations, we did not include additional sector dummies.
9. Because of missing values in survey responses, the sample size used for econometric analysis is much smaller than the original sample size. Of the 137 original responses, 26 did not provide information on the dependent variables. For the explanatory variables, most missing values are observed for *novelty* (46) and *complexity* (29).
10. We also tested the so-called parallel lines assumption, which implies that coefficients are identical across all categories of the dependent variables, and found no evidence that it is violated. Thus, we estimate simple ordered logit models rather than generalized ordered logit models.
11. Based on Wald tests, we combined the answers for the response categories 2 ('very low') and 3 ('low') for *equipment*.
12. To explore potential collinearity problems we calculated the variance inflation factors (VIFs). The mean VIF is 1.33 and the highest VIF of any of the explanatory variables is 1.74. In light of the conventional threshold levels of 5 or even 10, our findings do not appear to suffer from collinearity.
13. The findings of the robustness checks and of all other results not shown here due to space constraints are available from the authors upon request.
14. However, if these technology standards were very ambitious, countries might face a trade-off between technology transfer and emission reductions.

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Appendix 1 Excerpt from the survey questionnaire among CDM project participants

Questions on general characteristics of the company/institution

1) Please select the stakeholder type that most closely describes your role in the CDM project.
   - ☐ Transnational corporation
   - ☐ NGO
   - ☐ Bank / investor
   - ☐ Development agency
   - ☐ Government / authority
   - ☐ Consultant
   - ☐ Small and medium enterprise (SME)
   - ☐ University
   - ☐ Research institute
2) Please indicate the role of your organization in the CDM project with regard to technology ownership.

☐ Technology provider
☐ Technology recipient
☐ Supporting party of the technology provider(s)
☐ Supporting party of the technology recipient(s)

3) From the following set of climate technologies categorised by different application fields, please choose the ones that most closely describe the technologies that were relevant in your CDM project.
[Answers included 55 separate technologies grouped by the following application fields:
☐ Energy efficiency
☐ Energy supply
☐ Waste management
☐ Mobility
☐ Water
☐ Agriculture & nutrition]

Questions on selected technologies

4) Prior to the start of your project, how long had the selected technologies been on the market?
☐ n/a
☐ 0–2 years
☐ 3–5 years
☐ 6–10 years
☐ 11–15 years
☐ > 15 years

5) For the selected technologies, please choose their perceived complexity.
☐ n/a
☐ 1 (very low complexity)
☐ 2 (low complexity)
☐ 3 (medium complexity)
☐ 4 (high complexity)
☐ 5 (very high complexity)

Questions on technology transfer in the CDM project

In the following questions, we try to assess the characteristics of the technology transfer that occurred in your CDM project.

6) To what extent were equipment and technical components transferred to the receiving parties for the selected technologies?
☐ no transfer
☐ 1 (very low)
☐ 2 (low)
☐ 3 (medium)
☐ 4 (high)
☐ 5 (very high)

7) To what extent were knowledge and experience transferred to the receiving parties for the selected technologies?
    ☐ no transfer
    ☐ 1 (very low)
    ☐ 2 (low)
    ☐ 3 (medium)
    ☐ 4 (high)
    ☐ 5 (very high)
8) For your project, please estimate the degree to which the following channels are/were used for transferring technical equipment, knowledge and experience to the recipient parties.

Export:	Joint venture
☐ 1 (very low)	☐ 1 (very low)
☐ 2 (low)	☐ 2 (low)
☐ 3 (medium)	☐ 3 (medium)
☐ 4 (high)	☐ 4 (high)
☐ 5 (very high)	☐ 5 (very high)
Licensing / production or distribution of rights	Affiliated company / subsidiary
☐ 1 (very low)	☐ 1 (very low)
☐ 2 (low)	☐ 2 (low)
☐ 3 (medium)	☐ 3 (medium)
☐ 4 (high)	☐ 4 (high)
☐ 5 (very high)	☐ 5 (very high)

Appendix 2 Comparison of Survey Data to PDD Data (June 30, 2010)

	Survey (70 responses used in econometric analysis)	Survey (110 responses)	PDD (30 June 2010)		Survey (70 responses used in econometric analysis)	Survey (110 responses)	PDD (30 June 2010)
Region							
Asia	61.4%	60.0%	78.9%				
Africa	11.4%	12.7%	2.6%				
Latin America	24.3%	23.6%	13.8%				
Selected host countries							
Brazil	5.7%	4.5%	6.8%				
Chile	2.9%	1.8%	1.4%				

Continued

Appendix 2 Continued

	Survey (70 responses used in econometric analysis)	Survey (110 responses)	PDD (30 June 2010)	Survey (70 responses used in econometric analysis)	Survey (110 responses)	PDD (30 June 2010)
China	15.7%	16.4%	40.0%			
India	17.1%	17.3%	25.2%			
Indonesia	7.1%	6.4%	2.0%			
Malaysia	1.4%	1.8%	2.5%			
Mexico	2.9%	1.8%	3.3%			
Thailand	5.7%	3.6%	2.3%			
Vietnam	2.9%	1.8%	2.1%			
All others	38.6%	44.5%	14.4%			
Project type				Average project size (CO_2e/yr)		
Afforestation	1.4%	1.8%	0.2%	9,292	31,902	26,839
Biomass energy	12.9%	12.7%	12.9%	31,841	47,254	67,974
EE (Households)	2.9%	1.8%	0.6%	287,144	287,144	40,852
EE (Industry)	0.0%	2.7%	NA	–	3,338	–
EE (Own generation)	5.7%	9.1%	8.4%	85,549	75,228	132,383
EE (Supply side)	1.4%	1.8%	1.5%	41,162	346,500	388,323
Fuel switch	4.3%	4.5%	2.2%	623,947	575,548	397,817
Fugitive gas	1.4%	0.9%	0.7%	16,098	16,098	477,864
Geothermal	1.4%	0.9%	0.3%	66,713	66,713	222,085
HFCs	0.0%	0.9%	NA	–	1,434,143	–
Hydro	21.4%	18.2%	27.5%	84,407	77,946	109,965
Landfill gas	15.7%	15.5%	6.0%	252,081	223,225	154,841
Methane avoidance	7.1%	10.0%	11.4%	31,770	123,095	46,200
N_2O	0.0%	0.9%	NA			
Reforestation	4.3%	3.6%	0.8%	25,704	26,614	101,433
Solar	1.4%	2.7%	0.9%	3,500	1,978	22,402
Transport	1.4%	0.9%	0.5%	529,043	529,043	100,435
Wind	17.1%	10.9%	18.5%	92,506	85,050	91,732
Total	70	110	4,984	130,499	130,497	139,925