Intellectual property rights protection and the international transfer of low-carbon technologies*

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December 2021

Abstract

We examine the effect of intellectual property rights (IPR) protection on the two main channels of international transfer of low-carbon technologies i.e. trade in low-carbon capital goods, and foreign direct investments (FDI) by firms producing low-carbon technologies. Our data describes cross-country transfer through these channels between developing and developed countries in eight climate-related technology fields from 2006 to 2015. At the world level, we find that strengthening IPR protection increases transfer in six technology fields (solar PV, solar thermal, wind power, heating, lighting, and cleaner vehicles), while the effect is statistically insignificant in the others. However, when focusing on non-OECD countries, we find that stricter IPR do not influence trade in low-carbon capital goods but are a significant determinant of inward FDI for most low-carbon technologies. These results have important implications for climate negotiations on North-South technology transfer.

JEL codes: F18 O33, O34, Q54, Q55.

Keywords: Climate change; Technology transfer; Intellectual property rights protection; International trade; Foreign direct investment.

1. Introduction

Wide access to clean technologies is crucial to meet the Paris Agreement goal of limiting the increase in global temperatures to well below 2 degrees Celsius. With 90% of the increase in global carbon emissions until 2050 expected to occur in the developing world (Marchal, Dellink, Vuuren, & Clapp, 2012) while the vast majority of low-carbon technologies are still invented in developed countries, this is likely to require considerable international technology transfer, in particular from North to South. As an illustration, Japan, USA, Germany, South Korea, and France together accounted for 75% of the low-carbon inventions patented from 2005 to 2015.[1] Although it is both possible and desirable that developing countries become major innovators in low-carbon technologies, international technology transfer seems a necessary option, at least in the short run, to mitigate carbon emissions using the most cost-effective technologies.

The importance of technology transfer in global climate change mitigation efforts explains why the international diffusion of low-carbon technologies has been a cornerstone of climate negotiations since the adoption of the United Framework Convention on Climate Change (UNFCCC). Cross-country flows of technology have many determinants and are influenced by multiple policies related to scientific capabilities, innovation, trade, investment, environmental regulation, etc. Nonetheless, international negotiations have extensively revolved around the role of intellectual property rights (IPR) protection. The other main subject has been the financing of technology transfer. The UNFCCC Technology Executive Committee, which is the policy body where these discussions take place, has so far not delivered any policy recommendations on the design of a climate-friendly IPR regime (de Coninck & Sagar, 2015) and the Paris Agreement does not make any mention of intellectual property rights protection, indicating the lack of consensus on this subject.

International discussions on IPR are contentious (see Ockwell, Haum, Mallett, and Watson, 2010, for an analysis of early discussions and Glachant and Dechezleprêtre, 2017, for an update). On the one hand, developed countries see a strong IPR regime as a necessary condition for technology transfer. In their view, technology owners would not transfer technologies if they could not appropriate the related benefits. On the other hand, some developing countries (e.g. India) consider that strong IPR protection may hinder technology transfer (Abdel-Latif, 2015; Glachant & Dechezleprêtre, 2017). The argument is that strong IPR would prevent developing countries from

[1] Authors' calculations based on the PATSTAT database. Figure 1 illustrates the concentration of low-carbon inventions in OECD countries.

accessing green technologies at an affordable price since monopoly rights associated with IPR provide innovators with important market power. This debate echoes the theoretical analysis by (Maskus K. E., 2000) who identifies two countervailing effects of strong IPR protection, i.e., a positive market expansion effect because stronger IPR create a market for foreign firms whose intellectual assets are secured; and a negative market power effect because stronger IPR lead to higher prices. Given these two opposing effects, the net impact of stronger IPR protection is an empirical question.

Against this background, the main objective of this paper is to inform the policy debate with empirical evidence on the effect of IPR on the international transfer of low-carbon technologies. Broadly speaking, technology transfer is a process involving the building of technological capabilities leading to sustainable forms of economic development (Ockwell et al., 2008; 2018).

In practice, low-carbon technology transfer takes place through various market and non-market channels which convey codified knowledge and technology-intensive goods, but also soft skills, know-how, and tacit knowledge. In this paper, we consider two of these channels, i.e. international trade in capital goods that are used to reduce emissions (e.g. wind turbines, energy-efficient furnaces, electric vehicles), and foreign direct investment (FDI) by multinational enterprises that own low-carbon technologies (Glachant and Dechezleprêtre, 2017). These flows obviously do not provide a holistic picture of international technology transfer. However, it has been shown that they lead to significant productivity gains and innovation diffusion in the recipient economies (Xu, 2000; Branstetter et al., 2001, 2006; Görg and Strobl, 2005; Griffith et al., 2006; Haskel et al., 2007; Blalock and Gertler, 2008; Keller and Yeaple, 2013). Note also that both convey codified (i.e. patentable) knowledge, along with soft skills and know-how, which are key ingredients for developing countries to access effective climate mitigation technologies.

We use a newly assembled dataset covering international trade in low-carbon capital goods and foreign direct investment in eight low-carbon technologies across up to 140 countries in the period 2006-2015 to analyze the impact of IPR protection in recipient countries on low-carbon technology transfer. In addition, we examine how the impact of IPR varies between OECD and non-OECD countries and how the absorptive capacities of the recipient country influence the effect of IPR on technology transfer. Importantly, the data set includes both industrialized countries and emerging economies such as India and China.

We adopt a fixed-effects panel data approach where we exploit annual variations in technology-specific trade or FDI flows within a given country pair to identify how the level of IPR protection in the recipient country affects technology transfer. We find that strengthening IPR protection has a statistically significant positive effect on the transfer of most of the low-carbon technologies covered in this study, through either trade or FDI. The only exceptions are hydro power and insulation, in which a higher level of IPR has no significant influence. Importantly, we find that the magnitude of the impact of IPR is greater for low-carbon technologies than for the average technology. A possible interpretation is a tougher cross-technology competition than in other fields (i.e. pharmaceuticals).

This general result does not distinguish between developed and developing countries. Yet the key policy question is how to transfer more low-carbon technologies to developing countries. Therefore, we estimate additional models which yield specific results for this country group (which we identify by lower technological capabilities). We find a positive effect of IPR protection on FDI in six out of eight technology fields, i.e. hydro power, solar PV, solar thermal, heating, lighting, and cleaner vehicles. In contrast, IPR protection has no significant effect on trade towards developing countries. This difference between the two channels can be considered positive as FDI conveys more knowledge than trade.

To get a sense of the magnitude of these effects, we perform simulations based on our model of FDI flows. They show that if large emitters like India, Brazil, and Indonesia were to converge to the global mean level of IPR protection (which roughly corresponds to the level of IPR protection in China in 2015), low-carbon FDI deals would grow by at least 4% in India, 20% in Indonesia and 28% in Brazil. In short, if these large emitters converged to the Chinese level of IPR protection, it could make a significant difference in terms of international transfer of climate change mitigation technology.

The paper is organized as follows. Section 2 presents the conceptual framework on property rights and the international transfer of technologies. In Section 3, we explain our empirical strategy. We provide the data sources and descriptive statistics in Section 4. Econometric results are described in Section 5. We conclude in Section 6.

2. Conceptual framework

2.1. Literature

Our paper primarily contributes to the literature on the relationship between IPR protection and low-carbon technology transfer. Most of this literature provides anecdotal evidence and descriptive statistics (e.g. Barton, 2007; Kirkegaard et al., 2009; Ockwell et al., 2008; Glachant et al. 2013). We build on these qualitative pieces of evidence by conducting a quantitative analysis that allows us to control for confounding factors when evaluating the effect of IPR on the transfer of low-carbon technologies and to compare the different low-carbon technologies in a more systematic way.

To the best of our knowledge, Dechezleprêtre et al. (2013) have carried out the only econometric study estimating the impact of IPR (and other policies) on the international diffusion of low-carbon technologies. They use the count of patents filed by non-residents as a measure of technology transfer. Unsurprisingly, they find that tightening IP regimes promotes foreign patenting. However, this result is difficult to interpret as it can simply reflect that a stronger IPR protection leads inventors to switch from secrecy to patent protection, leaving the total amount of technology transferred unchanged (Cohen et al., 2000). Our data on trade and investment flows do not suffer from this potential substitution between patented and unpatented technology as these two channels convey both patented and non-patented knowledge.

2.2. The channels of international technology transfer

The diversity of channels through which knowledge crosses borders makes technology transfer inherently difficult to measure. In some cases, transfer is mediated by markets. It may also occur outside the market through knowledge spillovers. In the present study, we focus on two market channels, i.e. trade in capital goods and FDI.

Importing capital goods, such as machines and equipment, entails technology transfer because such goods embody technologies. Purchasing and using these goods enable the buyer to reap the benefit provided by the technology (Keller, 2004). International trade induces limited cross-border transfer of knowledge as such, because the specific knowledge to reproduce these goods remains in the originating country. Nonetheless, there is evidence that trade subsequently generates knowledge spillovers within the recipient economy through reverse engineering and business relationships (Rivera-Batiz and Romer, 1991). Exporters also usually offer a bundle which includes the capital good together with engineering services to install the device (Vandermerwe and Rada, 1988). Trade in pollution control equipment has long been used in the literature to analyze technology transfer of environmental technologies (see e.g. Lanjouw and Mody, 1996).

Foreign direct investment is another channel, as multinational enterprises typically give their foreign affiliates or partners in joint ventures access to their technology. FDI conveys more information than trade since the transfer covers not only the technology embedded in the goods or services that are locally produced by the subsidiary, but also the technology needed for this production. This means that, in contrast with the transfer of hard knowledge through trade, FDI improves the local capacities to imitate the technology, which is not without consequence for IPR. We will come back to this issue later on. Accordingly, FDI generates a larger number of spillovers, especially via the domestic circulation of skilled labor. There is strong empirical evidence that FDI causes the diffusion of technology and productivity growth in recipient countries (Xu, 2000; Branstetter et al., 2001, 2006; Görg and Strobl, 2005; Griffith et al., 2006; Haskel et al., 2007; Blalock and Gertler, 2008; Keller and Yeaple, 2013).

2.3. The ambiguous impact of intellectual property rights protection on international technology diffusion

The primary function of IPR is to provide greater innovation incentives, as knowledge has public good features: other economic agents may imitate the new technology, or at least learn from it, thereby appropriating a share of the innovation benefits. As mentioned previously, imitators can rely on reverse engineering; skilled workers can circulate between firms, taking their knowledge with them, etc. Granting intellectual property rights protection provides a policy solution to partly internalize these knowledge externalities. The patent is the best-known intellectual property. It ensures the exclusive commercial use of the invention for a determined period of time (typically 20 years).

Strengthening IPR protection has complex impacts on cross-country knowledge flows. On the one hand, the role of IPR – patents or trademarks – in facilitating the commercialization of new technologies can be especially strong in foreign markets, thereby promoting international technology diffusion. Appropriation is indeed more difficult abroad due to differences in legal systems and other factors. Foreign suppliers of technologies incur additional costs to monitor how partner firms and licensees use their technology (Keller and Yeaple, 2013). Contractual problems are also likely to be greater if the supplier and buyer of the technology operate in different countries. For instance, Antras and Rossi-Hansberg (2009) suggest that weak contract enforcement lowers the amount of technology transfer through outsourcing. Maskus and Penurbati (1995) refer to this positive role of IPR protection on technology transfer as the market-expansion effect. On the other hand, they also identify a market-power effect that goes in the opposite direction: IPR protection provides innovators with market power, giving the possibility to raise price barriers and reduce the market share of local imitators, thereby limiting technology diffusion.

To sum up, strong IPR protection increases the propensity to introduce a technology in a country (the extensive-margin effect) but, if introduced, it gives latitude to technology owners to reduce market size by raising price barriers and reducing the market share of local imitators (the intensive-margin effect). This trade-off between market expansion and market power implies that, on theoretical grounds, the net impact on technology transfer of stronger IPR is ambiguous (Maskus, 2000). In addition, its size (and sign) is likely to vary across technologies, industries, and countries because it is determined by the degree and nature of competition, the market size, and domestic technological capabilities (Mansfield, 1986; Orsenigo and Sterzi, 2010). This applies to low-carbon technologies as this category brings together very heterogeneous technologies that are implemented in very different sectors. A wind turbine has little in common with a LED light bulb or a cleaner vehicle, except that they all reduce carbon emissions. It justifies the reliance on technology-specific estimations below.

2.4. The case of developing countries

Climate negotiations on low-carbon technology transfer put a particular emphasis on developing countries, which thus deserves a specific analysis. These countries tend to have lower capabilities to absorb and adopt knowledge technology that more advanced economies (Lall, 1992). The ability to recognize, assimilate and apply new knowledge depends on factors such as the availability of researchers and engineers, a high number of past innovations, and high private and public R&D expenditures (Fagerberg, 1994; Keller, 1996; Worrell et al., 1997; Griffith et al., 2004; Kneller and Stevens, 2006). The net impact of strong IPR on technology transfer is likely to depend on the level of technological capabilities of recipient countries. If a country has low absorptive capacities, domestic firms are less able to imitate an imported technology. In this context, IPR are less useful in securing innovation returns, and thus in providing technology owners with incentives to transfer. This weakens the market-expansion effect of IPR protection and also reduces the market-power effect, as technology owners have latitude to raise their price even when IPR protection is weak.

3. Empirical strategy

The conceptual framework has two main implications for the empirical analysis. First, because low-carbon technologies are highly heterogeneous, we have to perform regressions at the level of each technology. Second, we need to empirically investigate the interactions between the level of IPR protection and the size of technological capabilities in order to derive insights on the specific impacts of IPR protection on developing countries.

3.1. The trade equations

To estimate the world-average effect of IPR protection on bilateral trade in low-carbon goods, we use the following gravity model:

$$TRADE_{ijkt} = \exp\left(\alpha_{0k} + \alpha_{1k} IPR_{jt-1} + \alpha_{2k} X_{ijt-1} + \delta_{ijk} + \gamma_{kt} + v_{ijkt}\right) \qquad (1)$$

where $TRADE_{ijkt}$ denotes the shipment value of low-carbon goods embedding technology k exported from country i to country j during year t. IPR_{jt} is the index of intellectual property rights protection in the importing country j, which we describe in detail below.

We exploit the panel structure of our dataset by using a fixed-effects estimator. More specifically, Eq. (1) includes a vector of country-pair fixed effects, δ_{ijk}, which control for any time-invariant characteristics that could be correlated with both IPR_{jt} and our dependent variables. In particular, it concerns country-pair characteristics typically used in gravity models, i.e. distance between the two countries, contiguity, common language, colonial ties, etc. as well as importer characteristics such as type of institution, type of regulation, industrial structure of the economy, development level, etc. In addition, we include year dummies to account for shocks common across all countries. As a result, we rely on annual variations in technology-specific technology flows within a given country pair for identification. To account for factors that vary over time and could be correlated with both IPR_{jt} and the dependent variable, we include a set of time-varying control variables in X. First, we control for the size and income of the exporting/investing country and the recipient country using GDP and GDP per capita, which is standard in gravity equations.

Second, we control for the recipient country's absorptive capacities, since this can influence the transfer of technologies and is likely correlated with IPR protection. These capacities are measured by enrolment in tertiary education as in Roper & Love (2006) and Castellacci & Natera (2013). Other proxies could be used such as the share of GDP allocated to R&D or the share of researchers in the population. In contrast with these two indicators, enrollment in tertiary education is available for almost all countries, which limits sample selection bias.

Third, we include the level of IPR protection of the exporting/investing country because exporting/investing firms may react differently to recipient countries' IPR protection depending on the IPR protection in their country of origin. Fourth, we control for the stringency of environmental regulations in both exporting and importing countries because it is a determinant of country-level supply and demand in low-carbon technologies. Finally, we control for whether the two countries have a free trade agreement in place or whether they belong to the same custom union in year *t*.

Fourth, we control for the importer's effectively applied tariff rate and the number of non-tariff measures for the low-carbon technology considered. Controlling for non-tariff measures is particularly important since many countries apply Local Content Requirements (LCRs) in the renewable sector (Kuntze and Moerenhout, 2013). LCRs are policy instruments that require foreign or domestic investors to source a certain share of intermediate goods from domestic manufacturers. Other things equal, LCRs have a negative impact on imports and might be correlated with IPR protection.

We lag all regressors by one year for two reasons. First, we expect that changes in IPR protection do not affect technology transfer instantly but after a necessary time for foreign suppliers and investors to react. Second, lagging the regressors mitigates endogeneity since IPR_{jt-1} should be less correlated with v_{ijt} and u_{ijt} than IPR_{jt} and some of the contemporary controls such as GDP contain the dependent variables.

In order to examine the specific impact of IPR protection on developing countries and the role of technological capabilities, we augment model (1) by introducing an interaction term between the recipient country's IPR protection and a dummy variable D_j as follows:

$$TRADE_{ijkt} = \exp\left(\alpha_{0k} + \alpha_{1k}IPR_{jt-1} + \alpha_{2k}\left(IPR_{jt-1} \times D_j\right) + \alpha_{3k}X_{ijt-1} + \delta_{ijk} + \gamma_{kt} + u_{ijkt}\right)$$

(2)

where D_{jk} denotes OECD membership. As explained before, we expect the effectiveness of IPR to increase with recipient countries' imitation capacities, which are arguably higher in industrialized countries.

Following Silva and Tenreyro (2006), Eq. (1) and Eq. (2) are estimated by the Pseudo Poisson Maximum Likelihood (PPML) estimator. The PPML estimator is less biased than the log-log OLS estimator under different assumptions regarding the data-generating process of the error term. PPML, unlike OLS, also accounts for outcomes equal to zero, which is a natural result of the Poisson distribution. These observations are dropped when a log-log transformation of model (1)-(4) is applied. The share of zeros in trade is 36% when pooling all trade across low carbon technology fields.

3.2. The FDI equations

The two equations are

$$FDI_{ijkt} = \exp\left(\beta_{0k} + \beta_{1k} IPR_{jt-} \quad + \beta_{2k} Y_{ijt} \quad + \rho_{kt} + u_{ijkt}\right) \tag{3}$$

$$FDI_{ijkt} = \exp\left(\beta_{0k} + \beta_{1k} IPR_{jt-} \quad + \beta_{2k}\left(IPR_{jt-} \quad \times D_j\right) + \beta_{2k} X_{ijt} \quad + \rho_{kt} + u_{ijkt}\right) \tag{4}$$

where FDI_{ijkt} is the number of FDI deals in low-carbon technology k made between parent companies located in country *i* and target companies located in country *j* in year *t*.

Eq. (3) and (4) show significant differences with the trade models. The structure of the FDI data does not allow the use of country-pair fixed effects. The prevalence of zeros leads to the exclusion of more than 90% of the observations from the estimation, corresponding to country pairs with no deals over the entire study period. As deals are mostly concentrated in OECD countries, this amounts to exclude almost all non-OECD countries from the analysis. The primary goal of this paper is to test whether IPR influences investment in low-carbon technologies towards developing countries. The resulting sample also becomes small with a low number of degrees of freedom.

Removing country-pair fixed effects creates an omitted variable bias. We mitigate this problem with the inclusion of four traditional time-invariant gravity control variables: logged distance between countries, contiguity, common language, and former colonial relationship. We keep the time fixed effects ρ_{kt}.

Other controls are included in the vector Y_{ijt} . Some of them are common with the trade models: the size and income of the exporting/investing country and the recipient country using GDP and GDP per capita, the recipient country's absorptive capacities measured by enrolment in tertiary education, the level of IPR protection of the exporting/investing country, the stringency of environmental regulations in both exporting and importing countries and whether the two countries have a free trade agreement in place or whether they belong to the same custom union.

Other control variables are specific. We include traditional determinants of inward FDI, such as the flexibility of business and labor regulations and the intensity of border regulations on the movement of capital and people. Table 6 in the Appendix provides the definition and the source of all variables.

Like the trade equations, the FDI models are estimated by the Pseudo Poisson Maximum Likelihood (PPML) estimator. In the present context, the estimator examines the impact on the probability of an additional FDI deal.

4. Data

4.1. Bilateral trade in low-carbon goods

Trade data come from the BACI database developed by the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII), which reports bilateral trade between countries at a highly disaggregated product level. BACI is based on the United Nations COMTRADE database. BACI's major advantage over the original COMTRADE is its ability to provide harmonized and more reliable bilateral trade data by matching declarations between exporting and importing countries (Gaulier and Zignago, 2010). We use the description provided by the 6-digit level of the harmonized system classification of products in BACI to identify equipment goods that incorporate technologies mitigating greenhouse gas emissions.[2]

We cover eight low-carbon technology classes across different sectors of the economy. Table 1 lists these technology classes. In the power generation sector, we cover hydro power, solar PV, solar thermal, and wind power. In the residential sector, the dataset includes various energy efficiency technologies, such as heating, insulation, and lighting. In the transportation sector, we cover electric and hybrid vehicles, hereafter referred to as cleaner vehicles. Our final sample covers trade data for 140 countries between 2006 and 2015. This accounts for around 88% of global trade in the selected technologies.

Table 1: List of low-carbon technologies covered

Sector	Technology class
Power generation	Hydro Solar photovoltaic Solar thermal Wind
Transport	Cleaner vehicles: hybrid and electric vehicles
Buildings	Heating Insulation Lighting

Note: In Appendix, Table 7 provides a harmonized system list of low-carbon capital goods for each technology.

[2] We choose the 1996 version of the harmonized system to maximize the number of years for which low-carbon goods are reported in the data.

4.2. Foreign direct investment deals in low-carbon goods

In contrast with trade data, accessing reliable FDI data at a disaggregated sectoral level is much more complicated, particularly in developing countries. The construction of this dataset is thus an important contribution of our paper.

We extract foreign direct investment data from the financial database Zephyr, provided by Bureau Van Dijk under a commercial license. Zephyr provides information on investment deals between acquiring companies and target companies. We use the number of investment deals between companies in the source country and companies in the recipient country in year t as an indicator of the intensity of FDI between country pairs. We would prefer to use the volume of investments, but this information is often missing, particularly for non-OECD countries. We use only completed deals of any kind including acquisitions, capital increases, minority stakes and share buybacks.

The main difficulty lies in identifying deals that presumably entail the transfer of a low-carbon technology. We apply two filters to select these deals. The first consists in keeping deals where the investing firm has filed at least one low-carbon patent in the recipient country. This is based upon the presumption that a firm only files a patent in a foreign country if it plans to commercially exploit the technology there. Because we use patents filed in a country that is different from the investing firm's headquarters, the family size of these patents is greater than one. Therefore, the vast majority of low-value patents, which are only filed domestically, are excluded in the selection process.[3]

Low-carbon patents are extracted from PATSTAT. We select patents classified under the "Y02" category developed by the European Patent Office and applied to all patents in PATSTAT. The Y02 category provides the most accurate tagging method of climate change mitigation patents available today and is the international standard for innovation studies in green technologies. Importantly, Y02 is a tagging system applied to all patents available in PATSTAT, across all patent offices in the world. We select patents that are related to the eight technologies included in the trade data. Table 8 provides a detailed description of these technology fields in Patstat. These low-carbon patents are then matched with Zephyr to identify the relevant investing firms. We thus obtain an indicator of FDI at the technology level, which makes it possible to compare the impact of IPR on the two transfer channels.

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[3] These patents thus have a family size greater than one. In this way, we exclude the vast majority of low-value patents as family size increases with patent quality (Squicciarini et al. 2013).

The second filter applies to the target firms. We keep deals in which the target firm belongs to an industry related to the technology. We match industry codes and low-carbon technologies based on the industry's label and the description of the patent category in Table 8. For instance, the description of the Solar PV category is "Solar photovoltaic (conversion of light radiation into electrical energy), including solar panels". Target firms operating in industries such as "2611 - Manufacture of electronic components" or "3511 - Production of electricity" are included in the computation of FDI deals related to Solar PV, while firms operating in "2751 - Manufacture of electric domestic appliances" are not.

In Zephyr, several country pairs exist with no deal in a given year. It is, however, risky to infer that no deals take place in reality: although Zephyr is one of the most reliable data sources of its kind, it does not claim to cover every single deal. Our general strategy is therefore to assume that the value is missing. We do however introduce an exception: we assume a zero when we observe deals for the same country pair in the preceding and following years. The final FDI sample contains 71 recipient countries observed yearly between 2006 and 2015.

In our data, we include investment deals made by a local investor. In our model, this allows firms to invest at home if the conditions are more attractive than abroad. Excluding domestic investment deals would lead to a severe sample selection bias. However, when using estimates to calculate marginal or average effects, we focus on cross-country investment.

4.3. Intellectual property rights protection

We measure IPR protection using the intellectual property protection indicator of the Executive Opinion Survey (EOS) produced by the World Economic Forum (WEF). The EOS asks each country to provide a representative sample of leading business executives to quantify the extent of intellectual property protection on a scale from 1 to 7. The random sampling follows a dual stratification procedure based on the size of the company and the sector of activity. The procedure ensures that both large and small firms representing the various economic sectors are captured in the final country-level score.

To measure the actual degree of intellectual property rights protection, we follow Maskus and Yang (2013) by interacting the WEF IPR index with the Fraser Institute's legal system index. We do so because a weak legal system de facto implies weak IP rights, regardless of a country's IPR strictness. The legal systems index is extracted from the Fraser Institute's annual reports on the economic freedom of the world (Gwartney et al., 2014). It is a composite index between 0 and 10 built from other indices and including legal enforcement of contracts, judicial independence, impartial courts, and the integrity of the legal system. In practice, we multiply the IPR index by the legal systems – which are complements – and rescale the product from 0 to 10.

4.4. Control variables

Data on GDP come from the World Development Indicators database maintained by the World Bank. Our proxy for stringency of environmental regulations is the Environmental Performance Index (EPI) maintained by Yale University. Data on tariff and non-tariff measures come from the TRAINS database maintained by UNCTAD. Data on freedom of FDI and movement of people, labor regulations, and burden of business regulations come from the Fraser Institute's Economic Freedom of the World 2015 dataset. Finally, gravity controls data such as bilateral distance, contiguity, common language, and colonial relationship come from the geodis dataset maintained by the CEPII. Table 6 provides the definition and sources for all variables.

5. Results

5.1. Average effect of IPR protection

Table 2 and Table 3 display the results of the estimation of model (1) for the trade of low-carbon goods and low-carbon FDI and by technology, respectively. In all regressions, the coefficients of the control variables have their expected sign when statistically significant, suggesting reliable estimates. An increase in GDP is associated with larger imports of low-carbon equipment and greater inward foreign investments; increases in GDP per capita lead countries to invest more capital abroad; increases in tariff and non-tariff measures reduce imports of equipment goods; the signature of a trade agreement increases trade between partners. Interestingly, trade agreements also reduce FDI. A likely explanation is that trade and FDI are substitutes: when trade barriers are high, firms are more likely to resort to FDI to reach a foreign market.

The effect of IPR protection on trade and foreign direct investment is positive at conventional significance levels for many technologies. This is true for the international trade of equipment for solar PV, solar thermal, wind power, and heating. In terms of magnitude, an increase in the IPR protection index of 1 unit (corresponding to more than twice the within-country standard deviation of the variable over our sample) is predicted to increase imports of solar PV by 55%, solar thermal by 11%, wind power by 54%, and heating by 9%. The effect on FDI is also statistically significant and positive for solar thermal, lighting, and cleaner vehicles. An increase in the IPR protection index by 1 unit is predicted to increase FDI in solar thermal by 26%, in lighting by 41% and in cleaner vehicles by 29%. These differences across technologies show the importance of industry-specific factors. For all these technologies, the market expansion effect of IPR protection thus more than compensates the negative impact through enhanced market power, leading to more transfer either through trade, FDI, or both channels.

Table 2: IPR protection and trade in low-carbon capital goods

	Hydro	Solar PV	Solar Thermal	Wind power	Heating	Insulation	Lighting	Cleaner vehicles
Importer IPR protection	-0.009	0.440**	0.101*	0.432**	0.086**	-0.01	-0.062	-0.146
	(0.117)	(0.215)	(0.052)	(0.173)	(0.035)	(0.038)	(0.087)	(0.141)
Importer Absorptive capacities	-0.79	-3.267	-0.645	-1.082	-0.760**	-0.542*	0.177	1.725
	(1.426)	(3.261)	(0.693)	(1.264)	(0.343)	(0.328)	(0.609)	(1.318)
Importer Log (GDP)	1.912**	1.688**	0.804	0.783	0.235	0.224	1.363***	0.058
	(0.820)	(0.741)	(0.593)	(1.095)	(0.203)	(0.357)	(0.391)	(0.988)
Importer Log (per capita GDP)	-5.654***	-0.101	-0.73	-0.949	0.18	0.934	-1.322	-0.903
	(1.512)	(1.358)	(1.028)	(3.258)	(0.376)	(0.583)	(1.044)	(1.889)
Importer Environmental Regulations	0.006	0.087	0.063	-0.119	0.02	-0.031	0.021	0.103
	(0.077)	(0.101)	(0.051)	(0.118)	(0.021)	(0.021)	(0.032)	(0.112)
Importer Effectively Applied Tariff	-0.093***	-0.043	0.007	-0.028	-0.020**	-0.026	-0.035*	-0.030***
	(0.020)	(0.050)	(0.018)	(0.025)	(0.010)	(0.018)	(0.018)	(0.004)
Importer Nr. of Non-Tariff Measures	0.004	-0.274***	-0.034*	-0.097	0.002	0.008	-0.023**	0.069
	(0.010)	(0.062)	(0.019)	(0.093)	(0.002)	(0.008)	(0.010)	(0.077)
Country pair in Trade Agreement (0/1)	-0.206	0.108	0.842***	0.135	0.337**	0.301**	-0.219**	-0.096
	(0.190)	(0.249)	(0.268)	(0.590)	(0.135)	(0.131)	(0.107)	(0.264)
Exporter Log (GDP)	0.01	0.009	0.206***	0.068	0.014	0.064*	0.05	-0.064
	(0.093)	(0.061)	(0.065)	(0.131)	(0.025)	(0.033)	(0.059)	(0.207)
Exporter Log (per capita GDP)	-0.514	-0.611***	-0.62	2.667	0.11	-0.205	0.458	3.762**
	(0.457)	(0.202)	(0.544)	(1.893)	(0.167)	(0.157)	(0.312)	(1.868)
Exporter IPR protection	2.276***	3.255***	1.451*	-3.316	0.495	1.321***	0.193	-9.099**
	(0.812)	(0.667)	(0.876)	(3.310)	(0.341)	(0.438)	(0.562)	(3.939)
Exporter Environmental Regulations	0.078	-0.059	-0.042	0.232*	0.083***	0.017	0.018	0.07
	(0.054)	(0.043)	(0.043)	(0.121)	(0.023)	(0.018)	(0.044)	(0.184)
Year fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-pair fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nr. Observations	15,423	25,301	16,132	9,410	27,033	20,824	19,535	13,231
Nr. Country pairs	1,872	3,102	1,946	1,093	3,328	2,526	2,393	1,651

Notes: robust standard errors clustered at the recipient country level in parentheses. * Significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. All columns are estimated with the Pseudo Poisson Maximum Likelihood Estimator with all regressors lagged one year. The dependent variable is the shipment value in low-carbon goods expressed in thousands of current USD.

Hydropower and insulation are the only exceptions for which IPR protection has neither a significant influence on trade nor on FDI. A possible interpretation is that they are more mature technologies that require less protection for advanced inventions. Another interpretation is that these technologies are the least patent intensive as shown in **Erreur ! Source du renvoi introuvable.**. Therefore, changes in IPR protection should have a smaller effect on hydro power and insulation.

We find that, for a given technology, IPR protection increases have a differential effect across channels.[4] For instance, strengthening IPR protection promotes the transfer of cleaner vehicle technologies through FDI but not through trade. The complexity of this technology offers a possible interpretation. In comparison with FDI, importing cleaner vehicles brings a small share of the vast knowledge needed to master the technology. IPR protection is thus a minor issue for exporters. In comparison, this suggests that IPR protection does matter for trade in wind power equipment and solar PV (Table 2) because they are simpler products, embedding more easily-imitable innovations.

Table 3: IPR protection and FDI in low-carbon technologies

	Hydro	PV	Solar thermal	Wind	Heating	Insulation	Lighting	Cleaner vehicles
Importer IP protection	0.078	0.176	0.230*	0.132	0.289	-0.049	0.342**	0.257**
	(0.107)	(0.124)	(0.139)	(0.125)	(0.199)	(0.213)	(0.167)	(0.114)
Importer Absorptive	1.212**	0.509	0.938	1.807**	-0.938	1.767*	-0.804	0.332
Capacities	(0.545)	(0.855)	(1.057)	(0.881)	(1.466)	(1.020)	(1.191)	(0.646)
Importer Log (GDP)	0.826***	0.820***	0.851***	1.038***	0.822***	1.032***	0.893***	0.880***
	(0.122)	(0.101)	(0.108)	(0.108)	(0.143)	(0.166)	(0.149)	(0.090)
Importer Log (per capita	-0.34	-0.025	-0.155	-0.723***	-0.175	0.13	0.374	-0.056
GDP)	(0.232)	(0.241)	(0.248)	(0.257)	(0.397)	(0.280)	(0.296)	(0.232)
Importer Environmental	0.002	-0.03	-0.017	0.028	0.016	-0.03	-0.079**	-0.045***
Regulations	(0.018)	(0.019)	(0.019)	(0.024)	(0.026)	(0.020)	(0.031)	(0.016)
Importer business	-0.07	-0.098	-0.154	0.067	-0.076	-0.104	-0.432	-0.415**
Regulations	(0.246)	(0.232)	(0.269)	(0.223)	(0.429)	(0.383)	(0.295)	(0.179)
Importer labor market	-0.096	-0.205***	-0.270***	-0.194***	-0.550***	-0.058	-0.348***	-0.127***
Regulations	(0.066)	(0.067)	(0.043)	(0.060)	(0.059)	(0.097)	(0.099)	(0.043)
Importer controls of capital	-0.118**	-0.096	-0.132	-0.184*	-0.187	-0.009	0.115	-0.025
and people movement	(0.058)	(0.094)	(0.114)	(0.096)	(0.163)	(0.125)	(0.098)	(0.080)
Country pair in Trade	-0.955***	-1.226***	-1.495***	-1.233***	-1.982***	-1.561***	-1.173***	-1.085***
Agreement	(0.240)	(0.298)	(0.329)	(0.290)	(0.417)	(0.463)	(0.414)	(0.277)
Exporter IP protection	0.243*	0.277**	0.261**	0.199*	0.369***	0.603**	0.292	0.261***
	(0.142)	(0.127)	(0.121)	(0.117)	(0.137)	(0.249)	(0.192)	(0.086)
Exporter Log (GDP)	1.478***	1.456***	1.267***	1.340***	1.225***	1.618***	1.719***	1.339***
	(0.109)	(0.131)	(0.110)	(0.122)	(0.115)	(0.135)	(0.144)	(0.073)
Exporter Log (per capita	0.694	0.816*	0.475	0.152	-0.143	1.961***	1.291***	0.754**
GDP)	(0.519)	(0.479)	(0.508)	(0.467)	(0.523)	(0.542)	(0.446)	(0.369)
Exporter Environmental	-0.113***	-0.141***	-0.074**	-0.046	-0.047	-0.225***	-0.220***	-0.121***
Regulations	(0.039)	(0.031)	(0.037)	(0.032)	(0.042)	(0.042)	(0.028)	(0.023)
Contiguity	-1.253***	-1.549***	-1.063***	-1.051***	-1.644***	-1.371**	-3.398***	-1.676***
	(0.355)	(0.368)	(0.388)	(0.312)	(0.477)	(0.583)	(0.578)	(0.379)
Common official language	0.759	1.046***	0.743**	0.935**	1.663***	0.881	1.666***	0.613
	(0.462)	(0.399)	(0.346)	(0.474)	(0.386)	(0.594)	(0.415)	(0.529)
Colonial relationship	-0.225	-0.200	-0.261	-0.226	0.015	-1.190***	-0.474	-0.113
	(0.366)	(0.312)	(0.292)	(0.389)	(0.484)	(0.372)	(0.344)	(0.258)
Log distance between most	-1.281***	-1.366***	-1.317***	-1.394***	-1.524***	-1.149***	-1.390***	-1.255***
populated cities	(0.154)	(0.118)	(0.117)	(0.145)	(0.131)	(0.166)	(0.170)	(0.096)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	23,055	24,037	23,583	25,666	22,469	17,839	18,679	23,791
Country-pairs	2,812	3,040	2,964	3,192	2,736	2,128	2,356	2,812

Notes: Robust standard errors in parentheses. * Significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. All columns are estimated with the Pseudo Poisson Maximum Likelihood Estimator with all regressors lagged one year. The dependent variable is the number of inward FDI deals computed from Zephyr and Patstat..

[4] Note that the sample used to estimate FDI models includes less countries. One should thus be cautious when comparing the numbers for FDI and trade.

5.2. OECD versus non-OECD countries

In Table 4, we present the results of models in which the IPR variable is interacted with the OECD membership dummy. Considering developing countries, the most important result is probably that the impact of IPR protection is never negative at conventional significance levels. Results however appear quite different for trade and FDI. The impact on imports of low-carbon capital goods is never statistically significant, while it is positive at conventional levels for FDI in all technologies with the exception of wind power and insulation.

This difference may stem from the size of knowledge transfer through the two channels. FDI bring to the recipient country the knowledge and soft skills that are necessary to produce the goods in which the technology is embedded.[5] In this way, FDI increase local technological capabilities, reinforcing the need of strict IP rights to deter imitation. In contrast, trade does not increase technological capabilities, at least in the short run. This does not preclude imitation: imported goods may be imitated through reverse engineering, but imitation needs to rely on pre-existing imitation capacities. As a result, the level of IPR protection may have less influence in low-capacity countries on the imports of capital goods than on inward FDI.

Table 4: Heterogeneous effect of IPR protection between OECD and non-OECD countries on trade in low-carbon capital goods and FDI in low-carbon technologies

		Hydro	Solar PV	Solar Thermal	Wind power	Heating	Insulation	Lighting	Cleaner vehicles
Trade	*Non-OECD*	0.196	-0.47	0.076	0.432	0.118	0.002	-0.082	-0.245
		(0.173)	(0.346)	(0.086)	(0.370)	(0.079)	(0.094)	(0.145)	(0.251)
	OECD	-0.211	0.827***	0.105*	0.432**	0.071**	-0.012	-0.054	-0.112
		(0.142)	(0.312)	(0.064)	(0.208)	(0.036)	(0.040)	(0.103)	(0.164)
FDI	*Non-OECD*	0.241*	0.359***	0.301**	0.207	0.593**	-0.077	0.759***	0.353***
		(0.146)	(0.126)	(0.140)	(0.147)	(0.236)	(0.275)	(0.197)	(0.121)
	OECD	0.051	0.148	0.219	0.124	0.27	-0.046	0.259	0.241**
		(0.116)	(0.130)	(0.149)	(0.129)	(0.211)	(0.236)	(0.166)	(0.121)

Notes: Robust standard errors clustered at the recipient country level in parentheses. * Significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. All columns are estimated with the Pseudo Poisson Maximum Likelihood Estimator with all regressors lagged one year. For clarity, the control variables are not reported in this table. The complete results are available in appendix (Table 8 and Table 9).

[5] We have computed the correlation between the average number of FDI deals for each recipient country (solar PV, solar thermal, wind, hydro) over the 2010-2012 period and the increase in renewable electricity production between 2010-2012 and 2013-2015 (source: The World Bank). The correlation coefficient is 0.33. This is not causal, but goes in the direction of our argument.

5.3. Simulating the effects of an increase in IPR in lax countries

Examining the marginal impact of a one-unit increase in the level of IPR protection, as presented above, is useful when comparing different channels, but it tells us little about how IPR protection impacts absolute levels of technology transfer. We thus conclude the discussion of our results with a simulation exercise in which we assume that countries below the median IPR protection level experience an increase in IPR protection to reach a global mean IPR level equal to 4.2. This average value roughly corresponds to the value of IPR protection in China in 2015 and involves a relatively small increase in IPR for large emitters such as India, Brazil, and Indonesia. Table 5 shows the impact of this change on low-carbon FDI deals for each country.[6] We use the coefficients obtained from the estimation of the model with the interaction terms between IPR protection and the OECD dummy because they consider the specificity of the developing countries that we focus on in the simulation.

Table 5: Effect of a minimum level of IPR on inward FDI in low-carbon technologies

Country	Change in IPR protection	% change in FDI deals					
		Hydro	Solar PV	Solar Thermal	Heating	Lighting	Cleaner vehicles
India	4%	4%	6%	5%	9%	12%	5%
Russian Federation	49%	39%	63%	51%	124%	181%	62%
Iran, Islamic Rep.	66%	49%	81%	64%	166%	250%	79%
Brazil	33%	28%	45%	36%	84%	118%	44%
Indonesia	22%	20%	31%	25%	56%	77%	30%
Thailand	52%	41%	67%	54%	134%	196%	66%
Kazakhstan	3%	3%	5%	4%	8%	11%	5%
Ukraine	72%	52%	87%	69%	180%	274%	85%
Argentina	76%	54%	90%	71%	189%	289%	88%
Egypt	113%	70%	121%	94%	269%	432%	118%

Notes: % change in FDI computed using the estimated coefficients in Table 7. Technologies for which there is no significant effect are not reported here. The CO2 emissions data come from UNEP (2016

We find relatively large impacts. For instance, FDI deals in India are expected to grow by at least 4% in six technologies. This figure equals 20% for Indonesia and 28% for Brazil. In short, if big emitters like India, Brazil, and Indonesia were to converge to the Chinese level of IPR protection, this would make a significant difference in terms of international transfer of climate change mitigation technology.

[6] We do not conduct the simulation on the trade channel as the effect of IPR is not significant for non-OECD countries.

6. Conclusion and policy implications

In this paper, we have combined data on international trade and FDI to analyze the impact of intellectual property rights protection on cross-border flows of climate change mitigation technologies. Our data cover up to 140 countries (both developed and developing) and include eight low-carbon technologies in the energy production, transportation, and building sectors. We exploit the fact that the level of IPR protection has evolved differentially over time across countries in our dataset to identify the impact of greater IPR protection, and to analyze how this impact varies with the recipient country's absorptive capacities.

At the global level, stricter IPR regimes are found not to impede the transfer of climate change mitigation technology. Strengthening IPR is found to increase the transfer of several low-carbon technologies through the following channels: imports of capital goods in solar PV, solar thermal, wind power, and heating; and foreign direct investments in solar thermal, lighting, and cleaner vehicles. Hydro power is the only technological field in which a higher level of IPR has no significant influence. Importantly, we find that the magnitude of the impact of IPR is larger for low-carbon technologies than for the average technology, illustrating the role that IPR protection could play to accelerate the international diffusion of climate change-mitigation technologies. One reason might be that cross-technology competition is tougher than in other fields (i.e. pharmaceuticals). These technologies are also probably more complex and modular -- a new product is composed of numerous separately patentable elements -- than the average technology. Both characteristics are expected to reduce the market power of technology owners.

The policy discussion on this issue primarily focuses on North-South technology transfer towards developing countries. Focusing on the country group with lower technological capabilities (using tertiary enrolment rates as a proxy), we find a positive effect of IPR protection on FDI in six out of eight technology fields: hydro power, solar PV, solar thermal, heating, lighting, and cleaner vehicles. In contrast, IPR protection has no significant effect on trade towards the same group of countries. Results are highly similar when considering the group of non-OECD countries.

Our interpretation is that FDI brings subsidiaries the knowledge and soft skills needed to produce the goods in which the technology is embedded. In this way, FDI increases local technological capabilities, reinforcing the role of IPR in deterring imitation. In contrast, trade does not increase technological capabilities, at least not in the short run.

The policy implications are substantial. In developing countries and for most of the low-carbon technologies considered, raising IPR protection would lead to increases in foreign investment, but not to more imports of innovation-intensive goods. That is not bad news, as FDIs convey knowledge and generates more spillovers in the recipient economy than trade in goods.

This delivers a clear-cut lesson for climate negotiations: relaxing IPR protection for low-carbon technologies appears in general to be counterproductive for low-carbon technology transfer towards countries with lower technological capabilities. Instead, increasing IPR protection induces more FDI, which yields two specific benefits for developing countries, i.e. more technology transfer in the short term, and higher technological capabilities in the long term.

Helping developing countries to build absorptive technological capacities through various means, including cooperative research, training, development and demonstration programs, is commonly viewed as other major means to promote cross-border knowledge diffusion. Our study suggests subtle interactions between this approach and the reinforcement of IPR protection. With higher technological capabilities, strong IPR protection will continue to increase inward knowledge flows but will also shift these transfers from the FDI channel to the trade channel.

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Acknowledgements

We thank Geoffrey Barrows and Arlan Brucal for very helpful comments on a previous version. We are thankful to Walter G. Park for providing the most recent version of the intellectual property rights protection dataset. Amadou Fall Ndoye provided excellent research assistance. The research leading to these results was supported by the Swiss National Science Foundation under the Sinergia programme, Project No CRSII1_147612; the Centre for Climate Change Economics and Policy; the Grantham Foundation for the Protection of the Environment.

Appendix

Table 6: Variable definition and data sources

Variable	Definition	Source
Dependent variable		
Shipment of low-carbon equipment	Volume of trade flows in low-carbon equipment between two countries.	Cepii's BACI database
Number of FDI deals	Number of deals between two countries where the investor owns a low-carbon patent in any country.	Bureau Van Dijk's Zephyr database and PATSTAT database
Regressors		
IPR protection index	This index is the multiplication of the WEF intellectual property right index and the Fraser Institute's legal system and property rights index. It is rescaled from 0 to 10.	World Economic Forum's Global Competitiveness Report and Fraser Institute's Economic Freedom of the World 2015
WEF IPR index	Score from 1 to 7 quantifying the extent of protection of intellectual property. The country-level score is obtained through aggregation of the surveys completed by executives randomly sampled.	World Economic Forum's Executives Opinion Survey
Legal system and property rights	This index is built from the aggregation of 4 components: (i) legal enforcement of contracts, (ii) judicial independence, (iii) impartial courts, and (iv) the integrity of the legal system.	Fraser Institute's Economic Freedom of the World 2015
Log (parent/exporter GDP)	Parent/exporter country's Gross Domestic Product in current USD.	World Bank's World Development Indicators
Log (host/importer GDP)	Recipient/importer country's Gross Domestic Product in current USD.	World Bank's World Development Indicators
Environmental regulations	Environmental Performance Index ranks 180 countries on 24 performance indicators across ten issue categories covering environmental health and ecosystem vitality.	Yale University
Effectively Applied Tariff	Simple Average of Effectively Applied Ad Valorem tariff computed at the technology level.	TRAINS
Number of Non-Tariff Measures	Number of imports and non-IPR related non-tariff measures computed at the technology level.	TRAINS
Freedom of FDI and movement of people (0 - 10 best)	The index is constructed through the calculation and aggregation of 3 indicators: (i) foreign ownership/investment restrictions, (ii) capital controls, and (iii) freedom of foreigners to visit.	Fraser Institute's Economic Freedom of the World 2015
Labor regulations (0 - 10 flexible)	The index is constructed through the calculation and aggregation of 6 indicators: (i) difficulty of hiring, (ii) flexibility of hiring and firing regulations, (iii) centralization of wage bargaining, (iv) rigidity of working hours, (v) mandated cost of worker dismissal, and (vi) military conscription.	Fraser Institute's Economic Freedom of the World 2015
Burden of business regulations (0 - 10 flexible)	The index is constructed through the calculation and aggregation of 6 indicators: (i) administrative requirements, (ii) bureaucracy costs, (iii) time and money required to start a business, (iv) extra payments frequency, (v) licensing restrictions, and (vi) cost of tax compliance.	Fraser Institute's Economic Freedom of the World 2015
Absorptive capacities	Enrollment in tertiary education	World Bank's World Development Indicators

Table 7: List of low-carbon equipment goods

Technology	Code in the harmonized system	Description
Renewable power generation		
Hydro power	841011	Hydraulic turbines & water wheels, of a power not > 1000kW
	841012	Hydraulic turbines & water wheels, of a power > 1000kW but not >10000kW
	841013	Hydraulic turbines & water wheels, of a power > 10000kW
	841090	Parts (incl. regulators) of the hydraulic turbines & water wheels of 8410.11-8410.13
Solar PV	854140	Photosensitive semiconductor devices, incl. photovoltaic cells whether/not assembled in modules/made up into panels; light emitting diodes
Solar thermal	841919	Instantaneous/storage water heaters, non-electric (excl. of 8419.11)
Wind power	850231	Wind-powered electric generating sets
Energy efficiency in building		
Heating	903210	Thermostats
	841861	Compression-type refrigerating/freezing equip. whose condensers are heat exchangers, heat pumps other than air conditioning machines of heading 84.15
	841950	Heat exchange units, whether/not electrically heated
Insulation	680610	Slag wool, rock wool & similar mineral wools (incl. intermixtures thereof), in bulk/sheets/rolls
	680690	Mixtures & articles of heat-insulating/sound-insulating/sound-absorbing mineral materials (excl. of 68.11/68.12/Ch.69)
	700800	Multiple-walled insulating units of glass
	701939	Webs, mattresses, boards & similar non-woven glass fiber products
Lighting	853931	Electric discharge lamps (excl. ultra-violet lamps), fluorescent, hot cathode
Other sectors		
Cleaner vehicles	870390	Vehicles principally designed for the transport of persons (excl. of 87.02 & 8703.10-8703.24), with C-I internal combustion piston engine (diesel/semi-diesel), n.e.s. in 87.03

Table 8: List of the technologies in the patent classification

Energy generation from renewable and non-fossil sources	
Hydro power	Hydro power stations; hydraulic turbines; submerged units incorporating electric generators; devices for controlling hydraulic turbines
Solar PV	Solar photovoltaic (conversion of light radiation into electrical energy), incl. solar panels
Solar thermal	Use of solar heat for heating & cooling
Wind power	Wind motors (mechanisms for converting the energy of natural wind into mechanical power, and transmission of such power to its point of use); blades; devices aimed at controlling wind motors
Emissions abatement and fuel efficiency in transportation	
Electric vehicles	Electric propulsion of vehicles; arrangement of batteries
Hybrid vehicles	Hybrid propulsion systems comprising electric motors and internal combustion engines
Energy efficiency in buildings and lighting	
Heating	Hot-water and hot-air central heating systems using heat pumps; energy recovery systems in air conditioning, ventilation or screening; heat pumps
Insulation	Elements or materials used for heat insulation; double-glazed windows
Lighting	Compact fluorescent lamps; electroluminescent light sources (LED)

Table 9: Effect of IPR protection on imports in non-OECD and OECD countries

	Hydro	Solar PV	Solar Thermal	Wind power	Heating	Insulation	Lighting	Cleaner vehicles
Importer IP protection	0.196	-0.470	0.076	0.432	0.118	0.002	-0.082	-0.245
	(0.173)	(0.346)	(0.086)	(0.370)	(0.079)	(0.094)	(0.145)	(0.251)
Importer IP protection x OECD	-0.407*	1.297**	0.029	0.000	-0.047	-0.014	0.028	0.133
	(0.226)	(0.573)	(0.123)	(0.462)	(0.090)	(0.098)	(0.170)	(0.299)
Importer Absorptive Capacities	-0.773	-3.909	-0.646	-1.082	-0.748**	-0.536	0.168	1.644
	(1.410)	(3.043)	(0.689)	(1.420)	(0.359)	(0.336)	(0.614)	(1.320)
Importer Log (GDP)	1.978**	1.744**	0.808	0.783	0.226	0.221	1.374***	0.103
	(0.822)	(0.749)	(0.601)	(1.101)	(0.197)	(0.353)	(0.394)	(1.017)
Importer Log (per capita GDP)	-5.710***	-0.105	-0.733	-0.949	0.188	0.937	-1.335	-1.01
	(1.573)	(1.287)	(1.033)	(3.225)	(0.373)	(0.578)	(1.070)	(1.971)
Importer Environmental Regulations	0.007	0.109	0.065	-0.119	0.017	-0.031	0.022	0.107
	(0.076)	(0.102)	(0.055)	(0.118)	(0.021)	(0.020)	(0.033)	(0.116)
Effectively Applied Tariff	-0.104***	-0.04	0.007	-0.028	-0.022**	-0.026	-0.035*	-0.029***
	(0.022)	(0.046)	(0.018)	(0.026)	(0.011)	(0.018)	(0.018)	(0.004)
Non-Tariff Measures	0.002	-0.224***	-0.033	-0.097	0.002	0.008	-0.022**	0.073
	(0.011)	(0.063)	(0.021)	(0.093)	(0.002)	(0.008)	(0.009)	(0.077)
Country Pair in Trade Agreement	-0.212	-0.004	0.834***	0.135	0.343**	0.304**	-0.219**	-0.1
	(0.187)	(0.233)	(0.280)	(0.591)	(0.139)	(0.129)	(0.105)	(0.257)
Exporter Log (GDP)	0.003	0.007	0.205***	0.068	0.014	0.064*	0.049	-0.056
	(0.091)	(0.060)	(0.066)	(0.130)	(0.025)	(0.033)	(0.059)	(0.205)
Exporter Log (per capita GDP)	-0.537	-0.736***	-0.622	2.667	0.111	-0.204	0.459	3.779**
	(0.463)	(0.186)	(0.541)	(1.900)	(0.168)	(0.158)	(0.314)	(1.871)
Exporter IP Protection	2.407***	3.547***	1.455*	-3.316	0.497	1.321***	0.189	-9.150**
	(0.831)	(0.618)	(0.870)	(3.322)	(0.342)	(0.438)	(0.565)	(3.931)
Exporter Environmental Regulations	0.071	-0.042	-0.042	0.232*	0.083***	0.017	0.018	0.069
	(0.055)	(0.035)	(0.043)	(0.122)	(0.022)	(0.018)	(0.044)	(0.183)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-pair fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nr. Observations	15,423	25,301	16,132	9,410	27,033	20,824	19,535	13,231
Nr. Country pairs	1,872	3,102	1,946	1,093	3,328	2,526	2,393	1,651

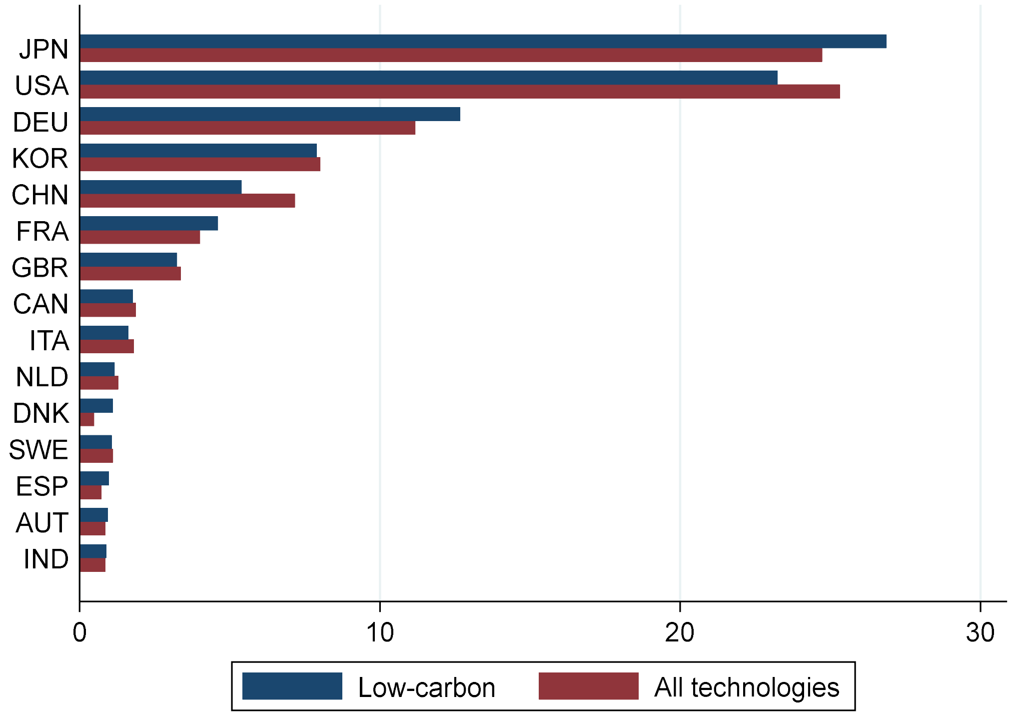
Notes: robust standard errors clustered at the recipient country level in parentheses. * Significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. All columns are estimated with the Pseudo Poisson Maximum Likelihood Estimator with all regressors lagged one year.

Table 10: Effect of IPR protection on FDI in non-OECD and OECD countries

	Hydro	PV	Solar thermal	Wind	Heating	Insulation	Lighting	Cleaner vehicles
Importer IP protection	0.241*	0.359***	0.301**	0.207	0.593**	-0.077	0.759***	0.353***
	(0.146)	(0.126)	(0.140)	(0.147)	(0.236)	(0.275)	(0.197)	(0.121)
Importer IP protection x OECD	-0.19	-0.211*	-0.082	-0.083	-0.323*	0.032	-0.501***	-0.111
	(0.148)	(0.122)	(0.135)	(0.122)	(0.193)	(0.359)	(0.189)	(0.128)
Importer absorptive capacities	1.399***	0.811	1.035	1.885**	-0.35	1.731*	0.167	0.496
	(0.499)	(0.826)	(0.982)	(0.880)	(1.407)	(0.993)	(1.148)	(0.605)
Importer Log (GDP)	0.787***	0.795***	0.841***	1.019***	0.821***	1.038***	0.848***	0.858***
	(0.127)	(0.104)	(0.115)	(0.116)	(0.136)	(0.163)	(0.150)	(0.097)
Importer Log (per capita GDP)	-0.118	0.209	-0.066	-0.624**	0.156	0.086	0.959***	0.063
	(0.257)	(0.261)	(0.312)	(0.275)	(0.466)	(0.588)	(0.343)	(0.223)
Importer environmental regulations	-0.004	-0.035*	-0.018	0.026	0.013	-0.028	-0.095***	-0.048***
	(0.019)	(0.020)	(0.020)	(0.024)	(0.026)	(0.024)	(0.029)	(0.015)
Exporter Log (per capita GDP)	-0.041	-0.071	-0.141	0.070	-0.082	-0.107	-0.362	-0.401**
	(0.265)	(0.236)	(0.275)	(0.226)	(0.421)	(0.401)	(0.292)	(0.189)
Importer labor market regulations	-0.058	-0.166**	-0.260***	-0.182***	-0.528***	-0.063	-0.233***	-0.101*
	(0.075)	(0.067)	(0.045)	(0.063)	(0.073)	(0.103)	(0.086)	(0.058)
Importer controls of capital and people movement	-0.079	-0.054	-0.115	-0.166*	-0.126	-0.014	0.199*	-0.003
	(0.072)	(0.100)	(0.122)	(0.099)	(0.157)	(0.153)	(0.104)	(0.094)
Country pair in trade agreement	-0.928***	-1.204***	-1.485***	-1.222***	-1.951***	-1.570***	-1.138***	-1.072***
	(0.245)	(0.299)	(0.326)	(0.284)	(0.414)	(0.495)	(0.422)	(0.277)
Exporter IP protection	0.232	0.264**	0.256**	0.194	0.348**	0.606**	0.272	0.255***
	(0.146)	(0.130)	(0.125)	(0.120)	(0.139)	(0.264)	(0.189)	(0.089)
Exporter Log (GDP)	1.479***	1.454***	1.269***	1.341***	1.231***	1.617***	1.694***	1.339***
	(0.108)	(0.128)	(0.109)	(0.121)	(0.111)	(0.136)	(0.139)	(0.073)
Exporter Log (per capita GDP)	0.697	0.816*	0.475	0.152	-0.153	1.959***	1.287***	0.753**
	(0.524)	(0.487)	(0.509)	(0.466)	(0.521)	(0.556)	(0.472)	(0.370)
Exporter environmental regulations	-0.110***	-0.138***	-0.073**	-0.044	-0.04	-0.225***	-0.212***	-0.119***
	(0.039)	(0.031)	(0.037)	(0.031)	(0.043)	(0.040)	(0.028)	(0.023)
Contiguity	-1.257***	-1.550***	-1.064***	-1.058***	-1.655***	-1.364**	-3.363***	-1.675***
	(0.361)	(0.376)	(0.389)	(0.315)	(0.468)	(0.601)	(0.570)	(0.386)
Common official language	0.727	1.025***	0.740**	0.932**	1.689***	0.88	1.560***	0.601
	(0.459)	(0.396)	(0.344)	(0.470)	(0.371)	(0.598)	(0.413)	(0.526)
Colonial relationship	-0.168	-0.161	-0.246	-0.202	0.087	-1.195***	-0.385	-0.087
	(0.377)	(0.324)	(0.295)	(0.384)	(0.496)	(0.345)	(0.392)	(0.261)
Log distance between most populated cities	-1.286***	-1.369***	-1.320***	-1.398***	-1.544***	-1.149***	-1.382***	-1.257***
	(0.155)	(0.119)	(0.119)	(0.146)	(0.141)	(0.166)	(0.168)	(0.097)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	23,055	24,037	23,583	25,666	22,469	17,839	18,679	23,791
Country-pairs	2,812	3,040	2,964	3,192	2,736	2,128	2,356	2,812

Notes: Robust standard errors in parentheses. * Significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level. All columns are estimated with the Pseudo Poisson Maximum Likelihood Estimator with all regressors lagged one year. The dependent variable is the number of inward FDI deals computed from Zephyr and Patstat data. The intellectual property rights (IPR) protection index is the intellectual property rights index from the World Economic Forum's Executive Opinion Survey multiplied by the legal systems and property rights from the 2014 Economic Freedom Dataset published by the Fraser Institute. Absorptive capacities are measured by enrollment in tertiary education. Importer business regulations, labor market regulations, and controls of the movement of capital and people come from the 2014 Economic Freedom Dataset published by the Fraser Institute. The country-pair trade agreement equals 1 if both countries are in a free trade agreement or a custom union based on the WTO Regional Trade Agreements Information System. Environmental regulations are measured by the Environmental Performance Index from Yale University.

Figure 1: Top 15 inventors of technologies



Note: Share of world's discounted stock of high value inventions in 2016. Authors' calculation from Patstat data