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Intellectual property rights and the international transfer of climate change mitigating technologies☆

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ABSTRACT

Our study is a quasi-replication of Dechezleprêtre et al. (2013), which was among the first studies to find a strong role for IPRs in explaining the international transfer of climate change and mitigation technologies (CCMTs). Their result is at odds with the received wisdom on the ambiguous role of IPRs in determining technology transfer to developing countries as strong IPRs can enable a market expansion effect and result in technology transfer but they may also strengthen monopoly power, increase value and reduce the incentive to transfer a large volume of technology. We extend the Dechezleprêtre et al. (2013) study by distinguishing between OECD and non-OECD groups of countries, including the effect of both *de jure* and *de facto* IPRs, and extending the period of study to include the years 2008–2018, when global trade and investment slowed down. Our exercise reveals that technology transfer to non-OECD countries is associated with a different set of policies compared to OECD countries. We also find that strong IP policies have not had the same beneficial CCMTs transfer outcomes in 2008–2018 as they did in the earlier period and in fact strong *de facto* IPR reduced the volume of CCMTs transfer to all countries.

1. Introduction

Limiting greenhouse gases (GHGs) emissions to prevent the global temperature from rising above 2 °C is widely recognized as a fundamental step to ensure a sustainable future, and the development and dissemination of low-carbon technologies is a key component in the battle to reduce the emissions of GHGs and to mitigate the risks associated to climate change. Much progress has been made on the development of new technologies. Probst et al. (2021) show that climate change mitigation technology (CCMT) patenting has consistently grown faster than patenting in other technologies since 1995, although the pace of patenting in the CCMT group has slowed since 2011. The vast majority of low-carbon technologies are still invented in developed countries and traded between developed countries, while 90 % of the increase in global carbon emissions is expected to occur in the fast-growing developing countries (Garrone et al., 2014). The international transfer of CCMTs to developing countries remains woefully small and has increasingly become a contentious policy issue.

Early studies on the transfer of CCMTs (see for example, Dechezleprêtre et al., 2013; Dechezleprêtre et al., 2011) show that the presence of stronger intellectual property rights (IPRs) greatly aided technology transfer of CCMTs. Among these studies, Dechezleprêtre et al., 2013—DGM (2013) hereafter—has been particularly impactful, having received 160 overall citations till May 2023 and widely used by multilateral policy organisations setting the agenda for climate change policy, such as the OECD, the Asian Development Bank and the IMF. In the last decade, DGM study has also had a huge impact on the use of patent data for studying climate change invention and diffusion. A very important methodological contribution of the paper is the justification and use of a patent-based measure of technology transfer, which

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measures both the precise technologies transferred and a count of many technologies that were transferred.

Theoretically, the DGM study rests on the favourable conditions for exports and international investment in CCMTs (and hence technology transfer in CCMTs) due to the increasing stringency of IPRs in the global economy. This is a well-known result in the literature on technology transfer, international trade and investment noted among others by Athreye et al. (2020), Ivus (2010), Park (2007) and Co (2004). Yet, it sits at odds with another equal robust theoretical and empirical finding in the literature on technology transfer to developing countries *viz.* that the transfer of technology due to stronger patent protection is theoretically and empirically ambiguous because it depends on the strength of market expansion and market power effects (Maskus, 2000). These effects in turn, have been shown to depend upon the absorptive capacity of nations and the size of the market open to innovators (domestic and foreign) in the focal country (Maskus and Penubarti, 1995). For many low-income countries, the weak absorptive capacity and small size of the domestic market is usually seen to favour market power effects (reflected in smaller volumes but higher prices).

Furthermore, the period since 2008 saw a shift in the economic environment surrounding the transfer of CCMTs in at least three respects: first, the international governance of climate change mitigation moved from targeted reductions by large polluters to voluntary reductions following the climate change summit at Copenhagen in 2009. Second, as Probst et al. (2021) show, this was followed by a slowdown in the annual growth rate of high value inventions in CCMTs – these fell from 10 % *per annum* from 1995 to 2012 to around 6 % *per annum* from 2013 to 2017. They identify a combination of factors such as declining fossil fuel prices, low carbon prices and increasing technological maturity for some technologies, such as solar photovoltaics as lying behind the new trend.[1] Lastly, the global financial crisis and the adoption of austerity measures in a number of developed economies adversely affected the economic environment for both exports and FDI. A shift in the technology transfer regime from 2008 is clearly visible in Fig. 1 where there is a noticeable slowdown in international transfer of CCMTs after 2009.

The difference in theoretical predictions from earlier schools of thought on technology transfer to developing countries and the changed circumstances since 2008 are two key reasons to ask if IPRs are working to transfer CCMTs since 2008, as they did in the early period from 1995 to 2007? We study this question by using a quasi-replication of the DGM (2013) study. Replication studies in social science are rare but also sorely needed (Bettis et al., 2016; Ryan and Tipu, 2022) as such studies help scientists to discern which of the results generated by empirical studies are truly robust, generalizable and replicable. Meaningful replications also extend the original estimations in different ways based on better coverage, new circumstances or the availability of new data (Bettis et al., 2016). In this paper, we replicate, but also augment the original DGM (2013) estimations in three ways. First, we add new measures of IP enforcement, which combine perceptions of IP protection and litigation data (Papageorgiadis and Sofka, 2020). They more accurately measure the cost of enforcement and thus the stringency of IPR– a key parameter in the DGM (2013)'s theoretical framework. IP law (*de jure* IPR*)* and IP enforcement (*de facto* IPR) can often diverge due to governance capability, political economy and other factors (Athreye et al., 2020; Papageorgiadis and McDonald, 2019; Jandhyala, 2015). Using *de jure* IPR instead of *de facto* IPR may overstate the contribution of IPR in the transfer of technology. As stricter patent enforcement measures usually strengthen the monopoly power of the innovator, we expect them to be associated with a lower volume of technology transfer. Second, we replicate the DGM (2013) estimations for OECD and non-OECD group of countries to better reflect the differences in technology transfer outcomes between largely developed and largely developing countries. Our third extension is motivated by the need to understand if IPR played the same facilitating role in the diffusion of CCMTs as it had done in 1995–2007 period due to a change in the governance and economic environment (noted earlier), post 2008.

Our findings from the DGM (2013) replication exercise for the period 1995–2007 are generally in line with those obtained in the original study. In particular, among the factors influencing the transfer of CCMTs, the effect of restrictions to international trade is negative, while the number of climate policies adopted in recipient countries, openness to FDI and strong *de jure* IPR have a positive effect on international technology transfer of CCMTs. However, we also find evidence that supports our extensions: slope homogeneity tests reject pooling OECD and non-OECD together and the inclusion of *de facto* IPR strengthens the *de jure* IPR effect (consistent with measurement error). Inclusion of the IP enforcement variable wipes out the effect of the climate policy variable in full sample estimates and for OECD countries, but non-OECD countries still show a positive influence of climate polices on CCMT transfer. Estimations at the technology class level are more mixed, especially when *de facto* IPR is introduced.

When we replicate the study for the later time period, 2008–2018, there is a dramatic reversal of the role played by IPRs in international CCMT transfer. In this period, all countries experienced a detrimental effect of strong enforcement on the number of patents transferred, consistent with the effect of strong market power on the volume of technology transferred. The overall negative effect of *de facto* IPR comes mainly from the effect of strong enforcement through courts—which we may expect to strengthen the market power of the innovating firm. Non-OECD countries experienced a negative effect of *de jure* IPR on technology transfer while in OECD countries this effect is positive and larger than before. Regressions at the technology class level are far more dramatic—they show no role for *de jure* IPR while *de facto* IPR consistently shows a negative effect on technology transfer.

Based on these results we conclude that although the IPR mechanism was important to the international transfer of CCMTs to developing countries in 1995–2007, their role has changed and since 2008 they pose a barrier to the transfer of CCMTs to developing countries. The remainder of the paper is organised in the following way. In the next section we explain the theoretical premises of the DGM (2013) model, review previous literature on technology transfer to developing countries and make some conjectures about the predictions of the DGM (2013) model when the shifts introduced by the more recent period is considered. We then describe the data, the empirical methodology, and detail the variable construction. In Sections 4 and 5 we describe the dataset we use, develop a descriptive statistical account of CCMTs transfer and report on the econometric estimations of the replication and extensions to the DGM model. We conclude with reflections on the implications of our results.

2. Technology diffusion of CCMTs and the role of strong IPRs

The economic literature addressing technology diffusion has identified three channels through which technologies are transferred among countries, namely: trade of goods that incorporate innovative technologies (in the case of CCMTs, for instance, wind turbines, photovoltaic panels or hybrid vehicles); FDI for sale of products embodying CCMTs; and licensing of patented CCMTs. However, transfer *via* licensing of patents is of much smaller magnitude compared to trade and FDI (Smith,

[1] This shift in patenting has also been noted by IEA (2019) thus: "Drawing upon new extractions from the Worldwide Patent Statistical Database (PATSTAT), researchers at the IEA and OECD have found that while patenting of innovations in climate change mitigation technologies (CCMT) related to power generation, transport, buildings, manufacturing, and carbon capture and storage (CCS) had generally been increasing much faster than other technologies in the period up to 2011–2012, there has been a notable drop-off in the number of these patents since then" (see *https://www.iea.org/commentaries/global-patent-applications-for-climate-change-mitigation-technologies-a-key-measure-of-innovation-are-trending-down*- last accessed 17-04-2023).

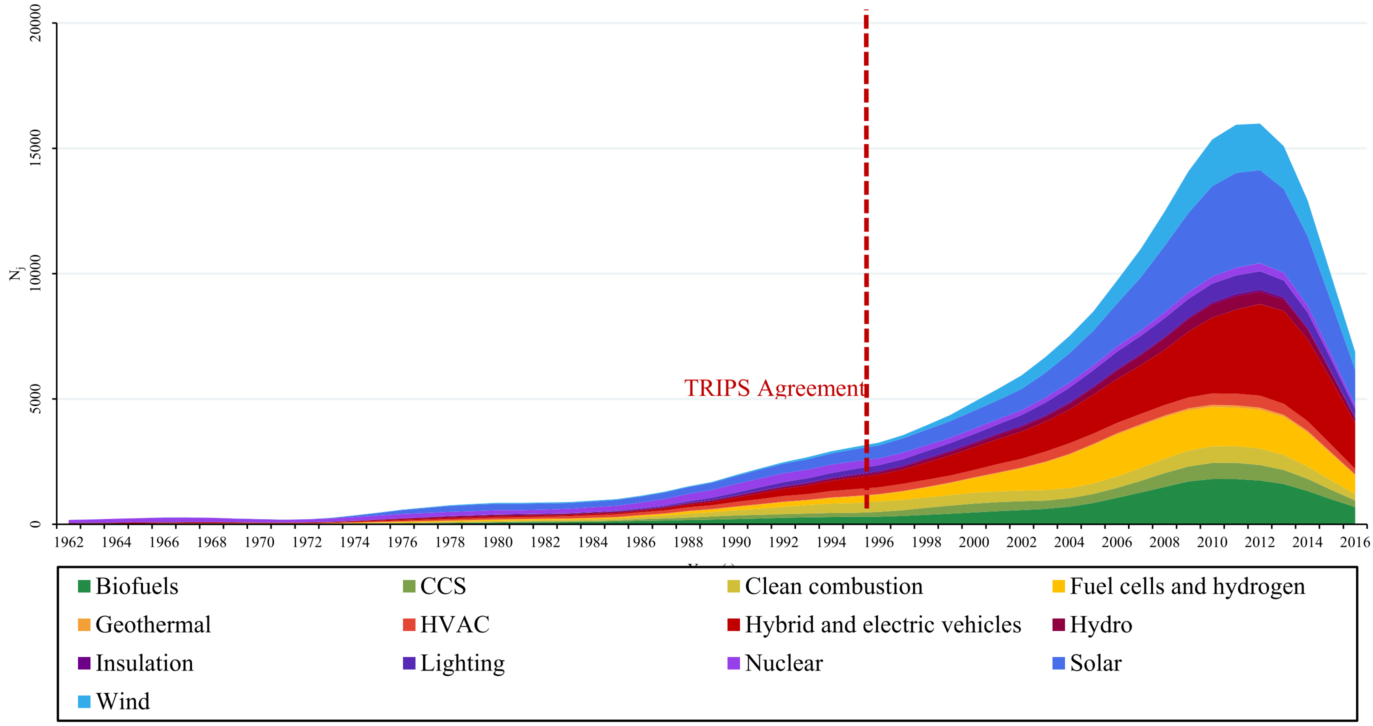

Fig. 1. Time trend of transferred patents (N_t), 5-year moving average, by technology, 1960–2018.
Source: Our re-elaboration on PATSTAT Online, Autumn 2018 edition data.
Note: Patent Law in books given by Park (2007) has been rescaled to 0 to 10 to be in congruence with Patent Law in practice and DGM (2013).

2001). Accordingly, in their seminal paper, DGM outline a model for technology transfer where technology is transferred through trade and FDI based on the profitability of selling technology-based products through either channel in some host country.

2.1. A brief exposition of the DGM (2013) model

In the DGM (2013) model (formal model is in the Appendix A), firms (owning inventions) patent abroad to protect their technology transferred through trade or FDI. A firm makes the decision to export or undertake FDI based on the costs of entry and price it can charge for its patented technology-based product. The cost of entering the market in country *j* through trade is usually lower than the cost of entering the same market with FDI. A larger market size may make foreign investment more attractive due to the potential for economies of scale in production. Whatever the chosen channel, the firm will protect itself against potential imitators in country *j* by patenting in the host country it wants to export to. Thus, patents held abroad proxy for the volume of technology transfers, although DGM (2013) also note that trade may be less patent intensive and so less dependent on IPR protection than foreign investment.

Among the factors that influence technology diffusion through trade and FDI, protection of IPRs plays a significant role in the DGM (2013) model. More stringent IPR prevents imitation by local firms and thus encourages both trade and FDI. Conversely, less stringent IPR allows some degree of imitative behaviour and shrinks the potential market for the invention in country *j*. This outcome is consistent with empirical work that has shown that strengthening IPR (such as through TRIPS) has definitely increased transfer of technologies to MNE subsidiaries (see Branstetter et al., 2006) and increased the value of technology exports to developing countries (Kanwar, 2012), but its effect on the volume of technology trade is more ambiguous. DGM argue that technology export can increase due to stronger IPR but equally, inventors may substitute foreign investment for exports rendering the net effect of trade on technology transfer more ambiguous.

Maskus (2000) showed that strengthening IPRs in a focal country elicits two contrasting effects on the willingness of foreign countries to export or invest in that country. On the one hand, increased IPRs strengthen the monopoly power of those who hold the rights over technology, rendering demand curves for technology more inelastic. Technology holders will be more willing to reduce the volume of technology to be transferred and to make a greater profit by increasing the value of the technology sold. This is sometimes termed as the *market power* or value effect. On the other hand, the increased IPR protection is a guarantee for the technology owners that others will not be allowed to profit from their patented technology. Being a deterrent to imitation and infringement, stronger IPRs exclude domestic competitors and expand the market share of foreign companies, making them more willing to increase the level of technology transferred—sometimes called the *market expansion* effect or volume effect.

Since these two effects are contrasting, there is no consensus on the effectiveness of IPRs in facilitating the diffusion of technologies and empirical testing has mostly confirmed this (Maskus and Penubarti, 1995). Their study also finds that 'market expansion' effect is likely to dominate in larger countries with strong technological abilities, while the 'market power' effect would dominate in smaller countries with weak technological abilities. Maskus (2000) notes however that the 'market power' and 'market size' effects may be moderated by other circumstances: for example, weak IPR protection need not remove an innovative firm's market power since imitation in the local market is likely to be costly and take time. Similarly, strong IPR protection need not create strong monopolies if local (product) substitutes are available. Other work such as Taylor (1993) who has looked at IPR and trade in technology has suggested that larger economies with significant technological capabilities may benefit from stronger IPRs in protecting their technology exports while market power effects may dominate in countries with weak technological capabilities.

Thus, the near consensus in claiming that stronger IPRs are able to attract more transfer of foreign technologies in the literature on CCMTs diffusion (Barton, 2007; Ockwell et al., 2008; Dechezleprêtre et al., 2013; Dussaux et al., 2018)[2] is in sharp contrast to the ambiguous results of stronger IPR protection on foreign technology transfer from more general models of technology transfer to developing countries. Furthermore, the consensus on the positive role played by IPRs in cross-country technology transfer is also at odds with the debate in multilateral forums like the UNFCC, where developing countries (notably India) claim that strong IPRs limit their access to low-carbon technologies by allowing companies and owners of cutting-edge technologies to keep prices prohibitively high (ICSTD, 2008).

Apart from the stringency of IPR, the other two parameters which influence the technology transferred through trade and FDI in the DGM (2013) model are the costs of entry through exports and foreign investment and the size of the market for CCMTs, both of which changed after 2008. Following the financial crisis, international trade greatly dampened. According to the World Trade Organization (WTO), in 2009 following the financial crisis, world trade flows decreased by almost 12 %. This happened due to the credit crunch, which increased financial constraints thus restraining production and reducing exports, due to the higher costs of borrowing. At the same time, following the Copenhagen Summit in 2009, the governance of climate change moved from a regime of mandated cuts in emissions (and a corresponding demand for CCMTs) to a regime of voluntary restraints in emissions resulting in a greatly reduced global market for CCMTs (as emissions could be higher than before). This shift in demand for CCMTs would have reduced the incentive for foreign investment. In the DGM (2013) model, it is also likely that smaller global markets favoured technology transfer through trade rather than FDI. Thus, the model would predict openness to FDI to be inversely related to technology transfer in the period since 2008. As trade is less dependent on IPR protection than FDI, so the effect of IPR stringency for technology transfer may also be more ambiguous.

2.2. Our proposed extensions

2.2.1. First extension(s) of the DGM model: measuring the cost of enforcement and de facto IPR

It is widely recognized (Branstetter et al., 2006) that measures of IPR traditionally utilized, such as the Ginarte and Park (1997) index, do not generally take into account the effectiveness of enforcement. The stringency of IPR protection facing an inventor critically depends on the costs of enforcement. When costs are high and enforcement is weak, inventors are faced with smaller markets and the potential for opportunistic behaviour from host country firms. Stronger enforcement has a direct effect on the profitability of technology trade as a major component of strict enforcement is the cutting down of counterfeit activity. In fact, stronger enforcement strengthens the monopoly power of the inventor. Improvements in the strength of property rights and administrative quality of the patent system also reduce the transaction costs associated with technology transfer and should enable more technology transfer.

De facto and *de jure* indices measure different things. *De jure* indices, given by Ginarte and Park, identify five general categories of statutory attributes that affect the extent and strength of national patent laws, based on participation in international agreements: (1) extent of coverage; (2) membership in international patent agreements; (3) restrictions or limitations on the use of patent rights; (4) enforcement provisions; and (5) the patent's term. They capture IPR intentions which can be a good signal of property rights protection—especially regarding coverage and patent term. Expanded coverage and extended patent terms can and did give rise to greater technology trade post TRIPS, as shown by Kanwar (2012). In contrast, *de facto* IPR indices, such as the Patent Enforcement Index developed by Papageorgiadis and Sofka (2020), are concerned with capturing the transactions costs associated with upholding a patent. These transaction costs may arise due to servicing costs of a patent (filing, renewing), strength of property rights administration and litigation costs of enforcing a patent through courts.

De facto measures are closer in spirit to the DGM (2013) theoretical model as they directly impact the profitability of exporting and/or investing in technologies. The DGM (2013) model would predict a positive sign on the coefficient of *de facto* IPR. However, from the buying country's perspective, the strengthening of market power of the inventor should always predict a smaller volume of technology transfer.

2.2.2. Second extension of the DGM model: the impact of country heterogeneity on technology transfer outcomes

In view of the trade literature which has emphasised country size and absorptive capacity as key variables in determining the direction of the IPR effect, it becomes important to distinguish the role of IPR on CCMTs in different country groupings based on their level of economic development. One such classification is membership of the OECD. Membership of the OECD is usually seen as belonging to the club of rich countries, while not being in the OECD marks most developing nations.

Distinguishing between developed and developing countries is also important as the divergence between *de facto* and *de jure* IPR is likely to be more pronounced for middle and low-income economies. Apart from IPR governance capability, which may be weak in developing countries, another reason for the divergence may lie in the political economy factors that emerged in the context of the TRIPS agreement (Jandhyala, 2015). In fact, the multilateral TRIPS agreement, signed in 1996, strengthened IPRs in many non-OECD countries that had also strongly contested the agreement. The final agreement recognized the role of national contexts in the implementation of TRIPS and many aspects of the patent enforcement regime were open to judicial interpretation in the different countries according to their national interest. While IPR harmonisation should have paved the way for greater technology transfer, the enforcement capacity of governments was highly variable and sometimes limited; consequently, weak IPR enforcement may have prevailed, whatever their *de jure* position may be.

Consistent with the theoretical and empirical literature we expect to find in our replication that market expansion effects of strong IPR dominate in OECD countries, while market power effects may dominate in non-OECD countries.

2.2.3. Third extension of the DGM model: extending the period of study to include 2008–2018

We know that while 1995–2007 witnessed an optimistic vision of globalisation and its ability to transfer knowledge, the mood changed dramatically after the financial crisis in 2009. In the area of CCMTs too, the TRIPS induced effect of technology trade due to the improved coverage of patentable sectors has slowly ran out of steam. In the policy sphere, conflicts over technology transfer became increasingly bitter and led to new mechanisms and arrangements such as the Clean Development Mechanism in 2004 to force technology transfer to developing countries in return for carbon credits to big polluters, and the establishment of the Clean Technology Fund (CTF) in 2008 to provide financial assistance to increase the adoption of climate friendly technologies. Donor countries CTF to Lower middle income and low-income countries could be classified as Overseas Development Assistance. These policy events suggest that market-based technology transfer was already reaching some limits by 2004. Finally, mandatory emissions targets were replaced by voluntary emission targets after the Copenhagen summit which may have reduced the demand for international CCMTs.

In the context of the DGM (2013) reduced form model, presented in the Appendix A, the financial crisis of 2009 raised the costs of entering a new market both through exports and through FDI. Thus, c_T and c_I increase in value, though the model imposes the constraint $c_I > c_T$. The comparative statics presented in Dechezleprêtre et al., 2013: 169) shows that an increase in costs of foreign entry will likely decrease the amount

[2] There are exceptions: Verdolini and Bosetti (2017) provide more nuanced evidence on the positive contribution of IPRs on CCMTs' diffusion by showing a diminishing marginal return on IPR protection for all technologies.

of technology transfer due to FDI and increase the amount of technology transfer through trade. If the costs of trading also increase, then effectively firms are left with selecting fewer but more profitable products to sell through both trade and FDI.

Secondly, as we have noted, the Copenhagen Accord loosened the binding targets of the Kyoto Agreement. Developed countries pledged less towards emissions reductions and so demand for CCMTs from this group of countries may have decreased and in turn this may have dampened technology transfer. To put this in perspective, OECD countries in general pledged moderate amounts of emissions reduction. Dellink et al. (2011: Table 1) report that European countries reductions were in the order of 20–30 % over 1990 levels, whereas scientists had recommended a 40 % decrease in emissions to avoid a rise in global temperatures. The US pledged a much lower amount than the EU (−17 % over 2005). In the reduced form model presented in the DGM (2013) paper, higher productivity products ($1\text{-}\ \Theta_1 > \Theta_0$) are sold in larger markets. The model permits us to investigate the effect of changed productivity but not of changed demand. However, the combination of higher costs of trade and dampened demand may have reduced the volume of technology transfer through FDI *via* a direct impact on market size. In turn, this means that the number of high productivity products that could be sustained by FDI (given C_I costs of entry) is lower.

Lastly, the comparative statics of the change in technology transfer due to a change in IPR rests on some assumptions, noted in the Appendix A. In the DGM (2013) model the positive effect of IPR on technology transfer rests on two assumptions made in the model. First, that the probability of weak enforcement (counterfeiting) is greater for trade than for FDI. Second, that the patent intensity of FDI is higher than the patent intensity of trade. However, both these assumptions may have wakened in the post 2008 period. Developing economies may have come up against governance issues in enforcement, so that IP protection for both trade and FDI weakened. As FDI was less forthcoming, trade may have been substituted for FDI. Our point here is that the comparative statics of the model presents a positive effect for IPR only under some conditions which have been noted by the authors themselves.

As the period after 2008 presented a different configuration of trade and investment related factors, it is worth investigating if the DGM (2013) model results on the positive role of IPR still hold in the later period of 2008–2018.

3. Empirical analyses

3.1. Methodology

We adopt the specification used by Dechezleprêtre et al. (2013) to analyse the international transfer of CCMTs, namely[3]:

$$\begin{aligned}CCMT\ Transfer_{ijt} = \ & \alpha k_{jt-1} + \beta_1 Policy_{jt-1} + \beta_2 Availability_{ijt-1} \\ & + \beta_3 Dejure\_IPR_{jt-1} + \beta_5 trade\_openness_{jt-1} \\ & + \beta_6 fdi\_openness_{jt-1} \\ & + \beta_7 GDP_{jt-1} + \beta_8 I_{kjt-1} + \psi_{ij} + \chi' \varphi_t + u_{ijt}\end{aligned} \tag{1}$$

Subsequently, we proceed with our extended models. First, we augment model (1) by including *de facto* IPR, which captures IP enforcement. Thus, we estimate Eq. (2) below:

$$\begin{aligned}CCMT\ Transfer_{ijt} = \ & \alpha k_{jt-1} + \beta_1 Policy_{jt-1} + \beta_2 Availability_{ijt-1} + \beta_3 Dejure\_IPR_{jt-1} \\ & + \beta_4 Defacto\_IPR_{jt-1} + \beta_5 trade\_openness_{jt-1} \\ & + \beta_6 fdi\_openness_{jt-1} \\ & + \beta_7 GDP_{jt-1} + \beta_8 I_{kjt-1} + \psi_{ij} + \chi' \varphi_t + u_{ijt}\end{aligned} \tag{2}$$

Second, we extend the analysis by re-estimating this model for sub-samples of OECD and non-OECD countries and third, for the later time period 2008–2018.

As we intend to do a quasi-replication, we have constructed and used the same variables as the original paper. As in the original study, we use a Poisson estimation as the dependent variable ($CCMT\_transfer_{ijt}$) is a count variable. We computed robust standard errors and clustered on country pairs as some country pairs are likely to show more intense technology transfer than others.

There are three small differences in the DGM (2013) estimations and ours which do not make a huge difference to the results but we note them here, in the interests of full disclosure. First, DGM (2013) use all the independent variables in levels with two variables in log (Availability and GDP), and few as a scale (IPR, tariff, fdi_control, policy), few as actual (Potential). As each of the data sources use differing measurement scales, data have been normalized using a standardization technique (z-scores) to transform them into a single scale with a mean of zero and a standard deviation of one. Second, in the DGM (2013) paper, only Availability and Potential are lagged by one period, while remaining independent factors are used contemporaneously. In our replication, all the variables are lagged by one period. Third, since DGM (2013) uses levels, they have also used year dummies (please see notes to Tables 4 and 5 in the DGM paper), the variables being normalized in our replication, we do not need to use year dummies. This however implies that we cannot compute pseudo-R^2 or marginal effects as computed by DGM (2013).

3.2. Data sources

We use patent data to measure the international diffusion of CCMTs[4] (*e.g.*, Dechezleprêtre et al., 2013; Haščič and Migotto, 2015). Namely, we relied on the European Patent Office (EPO) Worldwide Patent Statistical Database (PATSTAT), which identifies patents protecting CCMTs based on the International Patent Classification (IPC) and the Cooperative Patent Classification (CPC), which includes a dedicated patent tagging scheme for CCMTs, known as Y02/Y04S. This is currently the most accurate tagging method of identifying climate change mitigation patents and technologies (Dussaux et al., 2018).

Our complete database includes patents protecting 13 specific CCMTs, as detailed in Table 1. However, in order to run a proper replication of the DGM (2013) study, we restricted our sample to the same 10 technologies (indicated with "+" in Table 1) adopted by DGM (2013), to study transfer of CCMTs in 1995–2007.

Identifying the country of origin of a patent is not straightforward (Jaffe et al., 1993). There are at least three principles used to determine the origin of a patent: (i) assignment by priority country, *i.e.*, the country where the patent was filed for the first time; (ii) assignment by assignee country, *i.e.*, the country where the applicant resides; (iii) assignment by inventor country, *i.e.*, the country of residence of the inventor(s). Assignment by inventor country is the most frequently used of these three principles (OECD, 2008). Additionally, it better indicates where the technology the patent embodies comes from (Bergek and Bruzelius, 2010). For these reasons, we selected the assignment by inventor country principle to determine the country of origin of a patent.

Following this principle, it has been necessary to discard all patents filed in regional and international patent offices, since it is not possible to accurately assign a patent to a specific country if it has been filed in a patent office serving more than one country. In fact, from the moment a patent that is filed in an international office grants the applicant exclusive rights in all countries the office covers, such patent could be considered as filed in each national patent office of the countries the international office is serving. However, this process would more than duplicate the number of patents being analysed and overestimate the

[3] Please see Appendix A for a derivation of the formal model which justifies the use of the dependent variable.

[4] Pros and cons of patent data are well known; however, among the advantages of using this type of data, the most important is that patents can be easily disaggregated into specific technological fields.

Table 1
Selected Climate Change Mitigation Technologies (CCMTs) and CPC codes.

Technology	Description	CPC
Biofuels (*)	Technologies for the production of biofuels or fuels from waste; system integrating the use of such non-fossil origin fuels in transportation	Y02E 50/10; Y02E 50/30; Y02T 10/30; Y02T 50/678; Y02T 70/5218;
CCS (*)	Technologies aimed to capture, store, sequestrate or dispose of greenhouse gases (GHGs)	Y02C;
Clean combustion	Combustion technologies with mitigation potential	Y02E 20/00;
Fuel cells and hydrogen (*)	Fuel cells technology; its application in buildings and to transportation; systems combining fuel cells with production of fuel of non-fossil origin; technologies for the production of hydrogen including electrolysis with energy of non-fossil origin; application of the hydrogen technology to transportation	Y02B 90/10; Y02E 60/30; Y02E 60/50; Y02E 70/10; Y02E 70/20; Y02T 90/30; Y02T 90/40;
Geothermal	Technologies aimed to covert geothermal energy (e.g., for power production) and integration of such technologies in buildings	Y02B 10/40; Y02E 10/10;
HVAC (*)	Technologies for energy efficient heating, ventilation or air conditioning (HVAC)	Y02B 30/00;
Hybrid and electric vehicles (*)	Electric or hybrid propulsion systems for road, aeronautics, maritime transport for the transportation of goods or passengers; technologies to manage and store energy for electro-mobility; technologies related to electric vehicle charging	Y02T 10/62; Y02T 10/64; Y02T 10/70; Y02T 10/72; Y02T 30/12; Y02T 50/62; Y02T 50/64; Y02T 70/5236; Y02T 90/10;
Hydro (*)	Technologies aimed to covert hydro or tidal energy (e.g., for power production) and integration of such technologies in buildings	Y02B 10/50; Y02E 10/20; Y02E 10/30;
Insulation (*)	Architectural or constructional elements improving the thermal	Y02B 80/00;
Lighting (*)	Energy efficient lighting technologies	Y02B 20/00;
Nuclear	Technologies to generate energy of nuclear origin; application of such technologies to maritime transportation	Y02E 30/00; Y02T 70/5227;
Solar (*)	Technologies aimed to covert solar energy (i.e., photovoltaic, PV), solar thermal or thermal-PV hybrids) for heat and power generation; application of such technologies in buildings, home appliances or transportation	Y02B 10/10; Y02B 10/20; Y02B 40/18; Y02B 40/58; Y02B 40/74; Y02E 10/40; Y02E 10/50; Y02E 10/60; Y02T 30/40; Y02T 50/55; Y02T 70/5245;
Wind (*)	Technologies aimed to covert wind energy (e.g., for power production); integration of such technologies in buildings or transportation	Y02B 10/30; Y02E 10/70; Y02T 70/5254;

Source: Authors' elaboration on PATSTAT.
Note: (*) refers to technologies included in the replication exercise (i.e., the 10 CCMTs adopted by DGM (2013)).

number of domestic and transferred patents. Another option would be to consider a patent filed in an international office as shared among all its member countries, proportionally to a certain parameter. Verdolini and Bosetti (2017) who considered also the EPO as well as a receiving country, calculate all the variables in their empirical analysis as the weighted average of EPO's member variables, where the weights are based on the share of each country in overall EPO GDP. In order to reduce complexity and avoid subjective attributions, we excluded regional and international patent offices.

A further complexity comes from the fact that inventors of a patent are generally more than one and do not necessarily come from the same country. Therefore, several methodologies are used to define the origin of a patent according to the assignment by inventor country principle (Bergek and Bruzelius, 2010). Again, we adopted the definition most frequently used in the literature (Archambault, 2002), which is the first inventor assignment principle. This principle asks us to consider as the country of origin, the country of the first named inventor. Indeed, the first inventor is usually the most important contributor to the patent (Stolpe, 2002). Hence, a patent is considered domestic when the country of origin of the first inventor is the same country in which the patent is filed and transferred when they are different.

The CCMT dataset used in this paper is a patent level dataset. We have 47,212 (transferred) patent observations from 1995 to 2007 and 36,016 patent observations from 2008 to 2018. We identify 44 receiving countries and 177 originating countries in the final dataset. Of these 44 receiving countries, 27 belong to OECD and 17 are non-OECD countries. Each reported estimation table contains the total number of patent observations and the number of country pairs (combination of originating and receiving country) used in the estimations.

3.3. Variables and their construction

3.3.1. Dependent variable: international transfer of CCMTs

The dependent variable (*CCMT_Transfer*) is a proxy for the transfer of CCMTs in all the 10 technology groups (see Table 1), and it is measured as the number of patents N_{ijt} filed in country j by inventors from country $i \neq j$ in year t. This follows the theoretical model of DGM (2013), where technology transfer takes place through trade or FDI and patenting abroad occurs mainly to protect the technology from imitation by host country firms. Thus, the extent of technology or inventions transferred by trade and FDI is in fact the volume of non-resident inventions filed in country j. Other scholars studying international transfer of technologies such as Lanjouw and Mody (1996), and Eaton and Kortum (1999) have also used this measure. Unlike other measures used in the international technology transfer and diffusion literature such as Value of technology trade (Kanwar, 2012), Value of FDI in climate sectors (Dussaux et al., 2018) or Value of Royalty and License fees (Athreye and Cantwell, 2007), the patent-based measure is a count variable which can measure the number of technologies transferred. As the market expansion and market power effects are based on different predictions about volume, this count measure is helpful in making that inference. Further, patent data also allow us to count the number of distinct technologies transferred.

3.3.2. Explanatory variables

3.3.2.1. Strictness of climate policies ($Policy_{jt}$). The variable $Policy_{jt}$ captures the climate policies adopted in recipient country j and has been used in many previous studies (Johnstone et al., 2010; Garrone and Grilli, 2010; Nesta et al., 2014; Verdolini and Bosetti, 2017). Climate change policy instruments listed by the International Energy Agency (IEA) fall under six categories: (i) information and education; (ii) economic instruments; (iii) policy development and reforms; (iv) research, development and deployment (RD&D); (v) regulatory instruments; (vi) voluntary approaches. The variable $Policy_{jt}$ is a count variable ranging from 0 to 6 according to the number of climate change policy instruments listed by the IEA that country j has implemented in year t. As DGM (2013) note, the implementation of a new climate policy should increase technology inflows. Furthermore, counting the number of climate change related policies is comparable to the use of dummy variables to represent the introduction of new policies.

3.3.2.2. Stock of knowledge of the recipient country ($Availability_{ijt}$). The variable $Availability_{ijt}$ is a measure of the level of technological capabilities in the recipient country. Specifically, $Availability_{ijt}$ is country *j*'s discounted stock of technical knowledge in a specific technological area *i* in year *t*, computed according to perpetual inventory method. We have initialized the value starting from 1960, and used the following iterative formula:

$$Availability_{ijt} = (1 - d)Availability_{ijt-1} + N_{jjt}$$

Where *d* is the depreciation of R&D capital, set at 15 % as is usual in the literature (Keller, 2002; Dechezleprêtre et al., 2013), N_{jjt} is a measure of the technological capabilities independently acquired by country *j* in year *t.* Absorptive capacity has been traditionally measured by different indicators, *i.e.* the level of education, the number of patented inventions in a given country (Dechezleprêtre et al., 2013), research intensity (*e.g.* the percentage of R&D spending to GDP as in Co (2004)), or the number of scientists and engineers *per capita* (Belderbos et al., 2006). However, the use of patent data permits the computation of an indicator for the specific technological fields, as required by the present study.[5]

3.3.2.3. De jure and de facto strength of patent rights ($De\ jure\_IPR_{jt}$ and $De\ facto\_IPR_{jt}$). In order to proxy the strength of IPRs, we use the index developed by Ginarte and Park (1997) that measures the strictness of patent law. The index (*De jure*_IPR) is the unweighted sum of the countries' scores in five different aspects of patent protection (extent of coverage, membership in international patent agreement, and provision for loss of protection and enforcement mechanisms and duration of protection). As each of the five dimensions is rated from 0 to 1, the aggregate index thus ranges from 0 to 5. The index is available for 122 countries quinquennially from 1960 to 2015. In order to obtain a continuous variable, missing years have been filled with linear interpolation. Following DGM (2013), we re-scale the variable from 0 to10.

To take into account the *de facto* IPR protection we included the Patent Enforcement Index (PEI) developed by Papageorgiadis and Sofka (2020). Specifically, starting from the idea that firms experience transaction costs when interacting with a country's patent system, the authors refer to (and provide measures of) servicing costs, property rights protection costs and monitoring costs using a variety of different sources as shown in Table 2.

As each of the data sources use differing measurement scales, data have been normalized using a standardization technique (z-scores) to transform them into a single scale with a mean of zero and a standard deviation of one. Factor analysis was then used to discern the relationship between the different component variables of each of the constructs, and to inform the application of a weighting scheme derived from the factor analysis to aggregate the variables into a single numerical value for each construct. Finally, adopting a similar weighting scheme a composite index has been calculated for each of the 51 countries considered (with higher values - maximum of 10 - indicating stronger patent systems).[6]

3.3.2.4. Control variables. We control for other host and home country specific factors noted in DGM (2013). Specifically:

3.3.2.5. Size of recipient country (GDP_{jt}). The variable GDP_{jt} is the Gross Domestic Product (GDP) of country *j* in year *t*, measured in current US$. It is expected that the larger the receiving country, the larger the flow of technologies. Data for GDP are from the World Development Indicator database compiled by the World Bank. We also used GDP PPP measures but found the results were similar.

Table 2
Transaction costs of patent enforcement and construction of the Patent Enforcement index.

Cost type	Component of the patent system	Data and sources
Servicing costs	Quality of patent administration	Bureaucracy quality index (ICRG) "Bureaucracy does not hinder business activity" (WCY)
	Complexity, clarity & communication of patent related regulation & procedures	Darts-IP
Property rights protection costs	Judicial enforcement	"Judicial independence" (GCR) "Law and order" (ICRG) "Justice is fairly administered" (WCY)
	Upholding of patent rights in courts	Darts-IP
	Level of corruption in judiciary	Corruption perceptions index (Transparency International)
Monitoring costs	Effectiveness of policy enforcement Strengths of border controls	Country listings from the Special 301 Report (United States Trade Representative) (USTR)
	Opportunistic activities of non- practicing entities	Darts-IP
	Positive/negative perceptions of patent owners about national patent protection and enforcement levels	Intellectual property rights (WCY) Intellectual property protection (GCR)
	Cultural and societal attitudes towards the purchase of infringing goods	Global PC software piracy (BSA)
	Level of public commitment to patent protection	

Source: Based on Papageorgiadis and Sofka (2020), Table 1.

3.3.2.6. Trade openness ($trade\_openness_{jt}$). Barriers and restrictions to international trade may negatively affect transfer of technologies embodied in capital equipment goods. The variable $trade\_openness_{jt}$ is a country-specific index that captures barriers to international trade (Dechezleprêtre et al., 2013). The source of data is the Fraser Institute. Specifically, the index takes value 10 for countries with no specific barriers to international trade (*i.e.*, greatest openness), and zero for those imposing high taxes on international trade. The index is available for 162 countries quinquennially from 1970 to 2000, and annually from 2000 to 2016. Averaging from 1998 to 2017, the top five most open countries in our sample comprise Hong Kong (9.99), Singapore (9.81), Chile (9.33), New Zealand (8.96) and Australia (8.63) while the bottom five least open countries are the Republic of Korea (6.63), Malaysia (6.54), Argentina (6.51), the Russian Federation (5.74) and India (5.47).

3.3.2.7. Openness to FDI ($fdi\_openness_{jt}$). The variable $fdi\_openness_{jt}$ refers to the index of international capital market controls computed by the Fraser Institute, and it has been used as a proxy for barriers to FDI (*e.g.*, Dechezleprêtre et al., 2013). The index takes value 10 for countries imposing no barriers to FDI, and zero for those rising high barriers. As for $trade\_openness_{jt}$, also $fdi\_openness_{jt}$ is a proxy for the level of openness to FDI of country *j*. This index is available for 162 countries quinquennially from 1970 to 2000 and annually from 2000 to 2016. Averaging from 1998 to 2017, the top five most open countries in our sample comprise the Netherlands (8.56), Hong Kong (8.50), Ireland (8.48), the United Kingdom (8.08) and Denmark (7.83) while the bottom five least open countries are Colombia (3.75), the Philippines (3.61), China (3.19), India (2.99) and Ukraine (2.71). Here again, we rely on a simple count of barriers (for ease of interpretation) and do not transform the

[5] See DGM (2013), page 170. In the paper, some explanatory variables are defined in time t, and others in time t-1, although they are all lagged in the model specification. Please note that we describe all the explanatory variables at time t, but insert it in the estimation model with the time lag, t-1.

[6] We are very grateful to Nick Papageorgiadis for sharing these data with us.

variable in the way that the original DGM (2013) paper has done.

3.3.2.8. Number of inventions available for potential transfer (I_{it}). The variable I_{it} is a measure of the number of inventions available for potential transfer in year t from country i to country $j \neq i$. For each technology, it is computed as the number of patents filed anywhere in the world whose first inventor comes from country $i \neq j$ in year t (*First inventor* assignment principle). *Ceteris paribus*, the larger the number of patents filed by inventors from country *i*, the greater the likelihood that the technology protected by such patents will be transferred from country *i* to other countries. Patent data used to compute this variable come from PATSTAT.

4. Descriptive statistics

Table 3 reports the total number and the share of patents by the top 20 receiving countries and origin countries. Data show that, from 1995 to 2018, the top 10 receiving countries account for about the 90 % of all transferred patents and the first four countries (the UK, Korea, Germany and China) accounts for about 77 % of all patents transferred. Likewise, the distribution of patents by *inventors' countries of origin* (reported in Table 4) shows high concentration. In fact, the top 10 *countries of origin* account for about 87 % of patents, and the top four countries (the US, Korea, Japan and Germany) for about the 70 %, over 1995–2018. These trends are remarkably similar to those noted by Caravella et al. (2021).

Tables 5a–5c report descriptive statistics and correlation coefficients for the dependent, independent and control variables, for the full sample of observations and by OECD and non-OECD classification for 1998–2007, although as the *de facto* IPR data only start from 1998, we have to drop 19 countries.[7] Based on the mean values (0.22 patents per year) we can see that an average of one patent is transferred every five years during this period. As expected, technology transfer is higher among the OECD group of countries compared to the non-OECD group. On average, the latter group received one-fourth of the patents that OECD countries received. OECD countries have higher technological capability and more open trade and investment policies when compared to non-OECD countries. The correlation between variables within each country group gives no cause for concern.

Tables 6a–6c present the same data for the later period from 2008 to 2018. Overall, the average technology transferred doubled to about 1 patent every 2.5 years. Technology transfer was higher in the group of OECD countries but much lower in the non-OECD group. Compared to the earlier period, non-OECD countries received 1/6 of the patents registered internationally. As expected, the degree of openness is lower in the later period as many countries suffered due to the financial crisis and the slow-down of the global economy in its aftermath. The availability of technologies for transfer expanded quite quickly as did ownership of domestic technologies. Climate policies also showed a small increase in values compared to Tables 5a–5c, while the values of *de facto* and *de jure* IPR showed very small differences with Table 5a–5c in the extended period.

As we introduce *de facto* IPR as a measure of the stringency of IPR, it is worthwhile comparing it against the *de jure* IPR, to understand the relationship between the two. Fig. 2 plots *de jure* IPR (patent law in books) and *de facto* IPR (patent law in practice) for two years – 2005 and 2015 for OECD and non-OECD countries, respectively. Interesting differences emerge. *De jure* IPR and *de facto* IPR show higher values for OECD group of countries compared to the non-OECD group, although the variation in *de facto* IPR is higher than *de jure* IPR for both groups.

[7] The countries we dropped are: Bulgaria, Costa Rica, Cyprus, Dominican Republic, Algeria, Ecuador, Egypt, Guatemala, Honduras, Lithuania, Luxemburg, Morocco, Nicaragua, Peru, El Salvador, Tunisia, Uruguay, Vietnam, Zimbabwe. Tables 3 and 4 show that these countries are not major home or recipient countries of CCMTs.

Table 3
Number of patents by *Receiving country*, in the three periods considered.

Receiving country	1995–2007		2008–2018		1995–2018	
	No.	%	No.	%	No.	%
US	38,782	30.87	97,024	42.63	135,806	38.45
Korea	11,649	9.27	48,818	21.45	60,467	17.12
Germany	22,051	17.55	25,677	11.28	47,728	13.51
China	23,452	18.67	5850	2.57	29,302	8.29
Canada	7338	5.84	10,910	4.79	18,248	5.17
France	386	0.31	5922	2.60	6308	1.79
UK	1941	1.55	3906	1.72	5847	1.66
Russia	1973	1.57	3870	1.70	5843	1.65
Austria	4352	3.46	1302	0.57	5654	1.60
Spain	3188	2.54	1821	0.80	5009	1.42
Denmark	1787	1.42	3057	1.34	4844	1.37
Mexico	1416	1.13	2830	1.24	4246	1.20
Brazil	257	0.21	3810	1.67	4067	1.15
Poland	846	0.67	1488	0.65	2334	0.66
Portugal	869	0.69	829	0.36	1698	0.48
Norway	1109	0.88	533	0.23	1642	0.46
Singapore	41	0.03	1376	0.61	1417	0.40
Ukraine	483	0.38	846	0.37	1329	0.37
India	23	0.02	1097	0.48	1120	0.32
The Netherlands	642	0.51	409	0.18	1051	0.29
Rest of the World	3036	2.42	6210	2.73	9246	2.62
Total	125,621	100.00	227,585	100.00	353,206	100.00

Source: Our re-elaboration on PATSTAT Online, Autumn 2018 edition data.

Most OECD countries had high *de jure* IPR and corresponding high *de facto* IPR in 2005 and the same situation prevailed in 2015. There is a marginal decline in *de jure* IPR for OECD countries from 8.81 to 8.64 and small increase in *de facto* IPR from 7.0 to 7.14. Overall, the positive correlation between the two measures is strong with a correlation of about 0.6 for the OECD group.

For non-OECD countries, barring one country (Venezuela), there is a North-east movement from quadrant IV (moderate to high *de jure* IPR and low *de facto* IPR) to quadrant I (high *de jure* and high *de facto* IPR). For non-OECD countries, both *de facto* and *de jure* IPR has increased from 7.6 to 7.62 (*de jure* IPR) and 4.24 to 4.72 (*de facto* IPR) over the period. The values increase from 7.6 to 7.75 (*de jure* IPR) and from 4.4 to 4.96 (*de facto* IPR), respectively, if we exclude Venezuela. However, as the

Table 4
Number of patents by *Home country*, in the three periods considered.

Home country	1995–2007		2008–2018		1995–2018	
	No.	%	No.	%	No.	%
US	27,259	21.70	52,981	23.28	80,240	22.72
Korea	9815	7.81	45,268	19.89	55,083	15.60
Japan	21,841	17.39	32,002	14.06	53,843	15.24
Germany	20,486	16.31	31,677	13.92	52,163	14.77
China	16,747	13.33	9169	4.03	25,916	7.34
France	3403	2.71	10,339	4.54	13,742	3.89
UK	3627	2.89	6437	2.83	10,064	2.85
Canada	2764	2.20	3816	1.68	6580	1.86
Taiwan	1296	1.03	4200	1.85	5496	1.56
Denmark	1590	1.27	3335	1.47	4925	1.39
The Netherlands	2393	1.90	2158	0.95	4551	1.29
Spain	1361	1.08	3113	1.37	4474	1.27
Italy	1430	1.14	2392	1.05	3822	1.08
Switzerland	1343	1.07	1937	0.85	3280	0.93
Russia	1240	0.99	2021	0.89	3261	0.92
Austria	1181	0.94	1748	0.77	2929	0.83
Sweden	991	0.79	1321	0.58	2312	0.65
Australia	1071	0.85	1164	0.51	2235	0.63
Norway	928	0.74	1024	0.45	1952	0.55
Israel	499	0.40	1110	0.49	1609	0.46
Rest of the world	4356	3.47	10,373	4.56	14,729	4.17
Total	125,621	100.00	227,585	100.00	353,206	100.00

Source: Our re-elaboration on PATSTAT Online, Autumn 2018 edition data.

Table 5a
Descriptive statistics and correlation matrix, 1995–2007, Full sample.

		Mean	Std. Deviation	Min.	Max.	1	2	3	4	5	6	7	8	9
1	CCMT_Transfer$_{ijt}$	0.22	3.74	0.00	651	1								
2	Availability$_{jt}$	72.87	241.19	0.00	4,672.34	0.12	1							
3	*Dejure_IPR$_{jt}$*	7.70	1.55	1.58	9.75	0.04	0.26	1						
4	*Defacto_IPR$_{jt}$*	6.26	2.35	1.10	9.70	0.03	0.14	0.71	1					
5	Trade_Openness$_{jt}$	7.87	1.27	0.91	10	0.00	0.00	0.55	0.53	1				
6	FDI_Openness$_{jt}$	6.31	2.17	0.00	10	0.02	0.03	0.66	0.75	0.65	1			
7	Policy$_{jt}$	3.14	2.57	0.00	6	0.04	0.24	0.55	0.40	0.10	0.31	1		
8	I$_{jt}$	21.90	81.61	0.00	1,523.00	0.22	-0.02	-0.02	-0.02	-0.01	-0.02	-0.03	1	
9	GDP$_{jt}$	1,192.99	2,581.52	3.91	14,477.63	0.08	0.57	0.44	0.29	0.05	0.21	0.34	-0.05	1

Note: Shaded cells are correlation between *de jure* and *de facto* IPR measure.

Table 5b
Descriptive statistics and correlation matrix, 1995–2007, OECD countries.

		Mean	Std. Deviation	Min.	Max.	1	2	3	4	5	6	7	8	9
1	CCMT_Transfer$_{ijt}$	0.33	4.77	0.00	651	1.00								
2	Availability$_{jt}$	104.69	257.26	0.00	2,547.69	0.12	1.00							
3	*Dejure_IPR$_{jt}$*	8.62	0.88	5.30	9.75	0.04	0.37	1.00						
4	*Defacto_IPR$_{jt}$*	7.20	1.85	2.70	9.70	0.03	0.16	0.63	1.00					
5	Trade_Openness$_{jt}$	8.32	0.82	5.65	9.92	-0.01	-0.09	0.29	0.29	1.00				
6	FDI_Openness$_{jt}$	7.17	1.67	3.58	9.63	0.01	0.03	0.52	0.66	0.52	1.00			
7	Policy$_{jt}$	4.64	1.80	0.00	6	0.03	0.25	0.60	0.29	-0.01	0.14	1.00		
8	I$_{jt}$	19.19	76.48	0.00	1,523.00	0.25	-0.03	-0.02	-0.02	-0.04	-0.03	0.00	1.00	
9	GDP$_{jt}$	1,855.13	3,220.31	7.02	14,477.63	0.08	0.65	0.52	0.25	-0.04	0.15	0.28	-0.06	1.00

Note: Shaded cells are correlation between *de jure* and *de facto* IPR measure.

Table 5c
Descriptive statistics and correlation matrix, 1995–2007, non-OECD countries.

		Mean	Std. Deviation	Min.	Max.	1	2	3	4	5	6	7	8	9
1	CCMT_Transfer$_{ijt}$	0.08	1.43	0.00	154.00	1.00								
2	Availability$_{jt}$	29.71	209.94	0.00	4,672.34	0.12	1.00							
3	*Dejure_IPR$_{jt}$*	6.44	1.38	1.58	9.11	0.01	0.09	1.00						
4	*Defacto_IPR$_{jt}$*	4.25	2.02	1.10	9.30	-0.01	-0.03	0.38	1.00					
5	Trade_Openness$_{jt}$	7.24	1.50	0.91	10	-0.01	0.01	0.59	0.58	1.00				
6	FDI_Openness$_{jt}$	5.15	2.22	0.00	10	-0.05	-0.15	0.45	0.61	0.69	1.00			
7	Policy$_{jt}$	1.10	1.99	0.00	6	0.06	0.20	-0.16	-0.27	-0.33	-0.27	1.00		
8	I$_{jt}$	25.58	87.96	0.00	1,523.00	0.21	0.00	0.04	0.02	0.03	0.05	-0.03	1.00	
9	GDP$_{jt}$	295.14	487.97	3.91	3,552.18	0.13	0.52	0.02	-0.18	-0.18	-0.33	0.66	-0.03	1.00

Note: Shaded cells are correlation between *de jure* and *de facto* IPR measure.

large gap in values suggests, the correlation between the two measures is weaker for non-OECD countries at 0.3.[8]

5. Econometric findings

In this section, we explain our results. First, we discuss the results in tandem with DGM (2013) study. Subsequently, we discuss the extension results. The first sets of results, which are the replication of DGM (2013) model are reported in Column 1 of Table 7 and Table 8a (with each technology class separately). We report estimates at the technology class level because some of our theoretical reasoning (*e.g.*, market power) is microeconomic in nature and technology class estimates are more useful to disentangle such effects. In general, estimates across different technologies (Table 8a) and with all technologies considered together (column 1, Table 7) are relatively similar with coefficients exhibiting the same signs, although their size is different.[9] Both the control variables, *viz.* the number of inventions from the source country ($I_{kjt\text{-}1}$) and the size of the recipient economy ($GDP_{jt\text{-}1}$), have a positive effect on inward technology flows.

Similarly to DGM (2013) paper, we also look into the following policy questions.

5.1. Does accumulated knowledge facilitate the import of technology?

Our results show that technology absorption capacity ($K_{jt\text{-}1}$) facilitates greater technology transfer in only two technology classes (CCS and fuel cells) and in one it is at odds (Wind). This result is in contrast with what DGM find in their study as they found the variable has a significant negative impact on technology transfer in most of their regressions (7 out of 11). The effect of earlier inventions on local technological capabilities in a technology class could either be complementary in nature, as they may improve the local capacity to absorb new technology, or substitute in nature if they compete with imported innovations. Based on the sign and significance, we can say that complementary relation prevails in two industries and in one it competes. The coefficients show that a one standard-deviation increase of technology absorption capacity, which is large as it being a stock, leads to 21–30 % more patents for CCS and fuel cells and 18 % lower patents in Wind.

[8] One consequence of this large difference in mean values and the correlation coefficients is that the full sample results are prone to the “enhancement effect” noted by O’Neill (2019). Despite the lower correlation between the *de jure* and *de facto* IPR variables within each group, when these two groups are combined, the correlation between the two variables in the full sample is much larger.

[9] We should expect different coefficient sizes as we use a standardized variable while DGM use levels.

Table 6a
Descriptive statistics and correlation matrix, 2008–2018, Full sample.

		Mean	Std. Dev	Min.	Max.	1	2	3	4	5	6	7	8	9
1	CCMT_Transfer$_{ijt}$	0.44	9.18	0.00	1,500.00	1								
2	Availability$_{jt}$	286.49	883.65	0.00	8,119.34	0.13	1							
3	*Dejure_IPR$_{jt}$*	8.25	0.97	5.12	9.75	0.05	0.26	1						
4	*Defacto_IPR$_{jt}$*	6.04	2.26	1.00	9.30	0.03	0.12	0.67	1					
5	Trade_Openness$_{jt}$	7.68	1.12	3.33	10.00	0.01	-0.03	0.40	0.35	1				
6	FDI_Openness$_{jt}$	5.32	1.51	1.66	8.68	0.01	0.02	0.47	0.60	0.22	1			
7	Policy$_{jt}$	4.29	2.41	0.00	6.00	0.03	0.19	0.43	0.33	-0.15	0.22	1		
8	I$_{jt}$	46.13	187.58	0.00	2,823.00	0.19	-0.02	-0.04	-0.01	0.02	0.00	-0.05	1	
9	GDP$_{jt}$	2,127.21	4,034.57	4.42	19,390.60	0.09	0.50	0.46	0.19	0.17	-0.03	0.28	-0.06	1

Note: Shaded cells are correlation between *de jure* and *de facto* IPR measure.

Table 6b
Descriptive statistics and correlation matrix, 2008–2018, OECD countries.

		Mean	Std. Deviation	Min.	Max.	1	2	3	4	5	6	7	8	9
1	CCMT_Transfer$_{ijt}$	0.68	12.04	0.00	1,500.00	1.00								
2	Availability$_{jt}$	450.77	1,103.26	0.00	8,119.34	0.13	1							
3	*Dejure_IPR$_{jt}$*	8.81	0.64	6.83	9.75	0.05	0.22	1						
4	*Defacto_IPR$_{jt}$*	6.98	1.79	3.10	9.30	0.02	0.03	0.62	1					
5	Trade_Openness$_{jt}$	7.73	0.98	5.60	9.20	0.01	-0.09	0.44	0.22	1				
6	FDI_Openness$_{jt}$	5.67	1.15	1.76	8.68	0.00	-0.03	0.38	0.43	0.02	1			
7	Policy$_{jt}$	5.75	0.79	1.00	6.00	0.01	0.13	0.63	0.26	0.18	0.51	1		
8	I$_{jt}$	40.99	177.74	0.00	2,823.00	0.22	-0.03	-0.04	-0.01	0.02	0.00	-0.03	1	
9	GDP$_{jt}$	2,872.70	4,813.86	12.94	19,390.60	0.10	0.49	0.56	0.21	0.26	-0.07	0.15	-0.07	1

Table 6c
Descriptive statistics and correlation matrix, 2008–2018, non-OECD countries.

		Mean	Std. Dev	Min.	Max.	1	2	3	4	5	6	7	8	9
1	CCMT_Transfer$_{ijt}$	0.11	1.08	0.00	69.00	1								
2	Availability$_{jt}$	63.72	320.86	0.00	5,612.49	0.00	1							
3	*Dejure_IPR$_{jt}$*	7.49	0.82	5.12	9.35	-0.01	0.20	1						
4	*Defacto_IPR$_{jt}$*	4.21	1.96	1.00	9.20	0.00	-0.02	0.32	1					
5	Trade_Openness$_{jt}$	7.61	1.29	3.33	10.00	-0.05	0.06	0.42	0.55	1				
6	FDI_Openness$_{jt}$	4.84	1.79	1.66	8.47	0.02	-0.18	0.23	0.57	0.37	1			
7	Policy$_{jt}$	2.31	2.45	0.00	6.00	0.06	0.22	-0.18	-0.26	-0.48	-0.31	1		
8	I$_{jt}$	53.09	199.94	0.00	2,823.00	0.31	0.01	-0.01	0.02	0.03	0.02	-0.06	1	
9	GDP$_{jt}$	1,116.35	2,269.83	4.42	12,237.70	0.01	0.49	0.29	-0.11	-0.03	-0.25	0.56	-0.05	1

Note: Shaded cells are correlation between *de jure* and *de facto* IPR measure.

5.2. Do strict IPRs promote technology transfer?

Given the objective of the study, our results confirm the DGM (2013) model predictions that a strong IPR (*de jure*) has a significant impact on technology transfer. We find the significant impact in all but insulation and clean combustion technology classes. Similar to what DGM (2013) has found, the impact of strict *de jure* IPRs on technology transfer is fairly large. Based on the coefficient values, we can say that an increase in *de jure* IPR by one standard deviation brings 28 to 90 % more patents.

5.3. Do trade barriers hinder technology transfer?

DGM's theoretical prediction with respect to the role of tariffs in affecting technology transfer is somewhat ambiguous as they argue that the effect is often compensated by FDI, which is more patent intensive (DGM, 2013: 174). Our estimations show a highly significant negative impact of trade openness on technology import for all the technology classes. This suggests that firms may be using other channels to transfer technology even if trade barriers are low. The coefficients also allow us to compare the relative importance of trade openness *versus de jure* IPR. As expected, trade openness has a smaller negative influence than the positive influence of *de jure* IPR on inward technology in the receiving country.

5.4. Do restrictions on FDI hinder technology transfer?

Our results are in complete contrast to what DGM (2013) predicted and found. We find that more FDI openness in a country induces firms to circumvent this by registering more patents. DGM (2013) however found that more FDI restriction reduces technology transfer. What explains this divergence? We would argue that in receiving country, controls on FDI induces firms to look for alternate channels of technology control and transfer. The more the firm can control its technology, the more that technology is transferred through patenting activity.

5.5. Do climate policies promote technology transfer?

In line with the expectations, we find a positive impact of climate policies on technology transfer for most (six of the ten) of the technology classes and overall for all CCMTs. Ideally, we should have used the extent of implementation of climate policies rather than mere enactment, but such data are not available on a comparable basis for all technologies.

5.6. Extensions

As mentioned, we carry out the following three extensions: a) distinguishing between *de jure* and *de facto* IPR; b) categorizing recipient country based on OECD membership; c) accounting for climate-regime shift with analysis for the more recent period. The first and last extensions are carried out for combined CCMTs and each technology class separately, whereas the second extension is only for combined CCMTs. Here is our description of the results.

5.6.1. Does patent enforcement matter?

Column 2 of Table 7 reports the results for complete CCMTs while

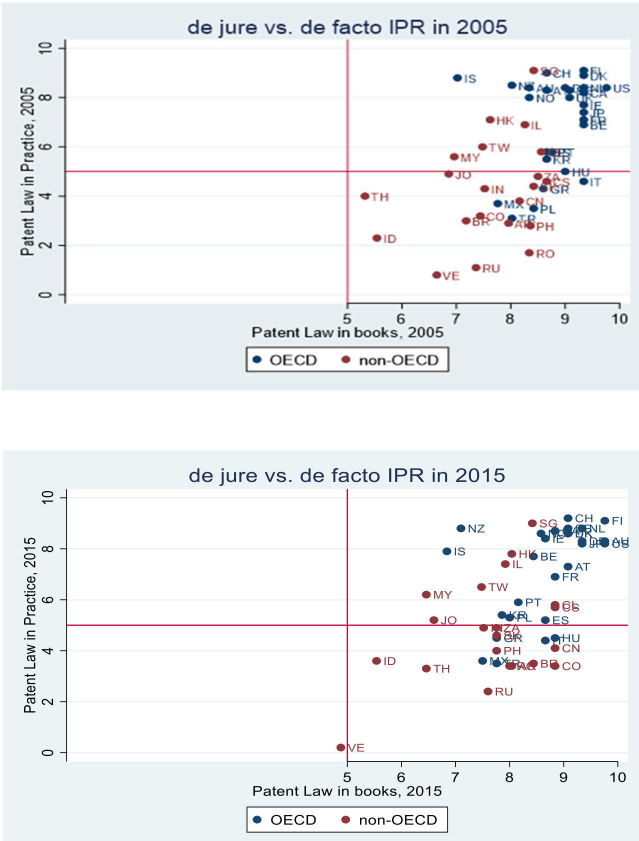

Fig. 2. Country plot of IPR systems of 48 countries for 2005 and 2015 with countries divided on the basis of membership of OECD.
Data Source: For Patent Law in books for 2005 (Park, 2007), own compilation for 2015; for Patent Law in practice for 2005 and 2015 (Papageorgiadis and McDonald, 2019).
Note: Only countries that had values for dejure and defacto IPR in both 2005 and 2015 are plotted in this figure.

Table 8b reports the results of including *de facto* IPR (along with *de jure* IPR) for each technology class separately. To assess whether the coefficient of *de facto* IPR is statistically different from zero, a Wald test was performed. The last row of Table 8b reports that for most specifications, *de facto* IPR is different from zero, thus warranting its inclusion. We find that the coefficient of *de facto* IPR is significantly different from zero in seven of the total 11 regressions. Importantly, wherever it is statistically significant, its coefficient value is higher than *de jure* IPR. This implies that inventors value more the *de facto* IPR than *de jure* IPR. In two technology classes - hydro and solar, *de facto* IPR does not influence technology transfer. The probable reason could be the nature of these two technologies - Hydro being more mature with most IPR rules framed and enacted and Solar being the recent focus of CCMTs, the framing of rules is given more importance than enacting the rules.

The only variable that loses significance with introduction of *de facto* IPR is the climate policy variable. As discussed earlier, our measure is mere enactment of climate policy rather than implementation. Firms with inventions may value *de facto* IPR as means to protect and grow potential markets much more than climate policy. Moreover, the countries that signed up to stronger IPRs also led in terms of climate policies as the membership of these international agreements had a strong overlap.

5.6.2. *Does country development matter?*

A key issue with DGM (2013) paper is that it does not distinguish the development stage of the receiving country. An abundant literature suggests that developing countries receive inferior technologies, or incomplete transfer of technology. Firms are also not willing to transfer technology, when the receiving country is perceived as more risky, because it lacks IPR protection, has a different governance structure, and is poor. We have also argued that in such countries the extent of technology transfer would be lower because market power effects will dominate.

We test this by dividing the full sample into two categories – OECD member countries and non-OECD member countries. We first carry out a slope homogeneity test (reported in last row, Table 7) to see whether the two groups represent different sampling groups. We find that slope homogeneity is rejected.

Columns 3 to 7 report the results for OECD and non-OECD group of countries without and with inclusion of *de facto* IPR. Interesting

Table 7
Econometric findings, 1995-2007, Full sample with countries divided based on OECD membership.

	Full sample		OECD countries		Non-OECD countries	
Variables	(1)	(2)	(3)	(4)	(5)	(6)
$Availability_{ijt-1}$	0.02	0.02	0.10***	0.06*	0.00	0.01
	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)	(0.02)
$Dejure\_IPR_{jt-1}$	0.51***	0.30***	0.68***	0.79***	0.69***	1.06***
	(0.07)	(0.07)	(0.09)	(0.13)	(0.12)	(0.14)
$Defacto\_IPR_{jt-1}$		0.64***		0.56***		0.173
		(0.11)		(0.10)		(0.156)
$Trade\_openness_{jt-1}$	−0.33***	−0.41***	−0.23***	−0.23***	−0.34***	−0.68***
	(0.04)	(0.03)	(0.02)	(0.02)	(0.07)	(0.09)
$FDI\_openness_{jt-1}$	0.37***	0.46***	0.46***	0.41***	−0.35***	−0.16
	(0.06)	(0.05)	(0.05)	(0.04)	(0.08)	(0.12)
$Policy_{jt-1}$	0.23***	0.04	0.21***	0.05	0.21***	0.10*
	(0.04)	(0.04)	(0.03)	(0.03)	(0.05)	(0.06)
I_{kjt-1}	0.09***	0.07***	0.06***	0.05***	0.14***	0.149***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
GDP_{jt-1}	0.72***	0.90***	0.94***	1.13***	−0.25***	−0.37***
	(0.08)	(0.09)	(0.11)	(0.12)	(0.07)	(0.07)
Observations	47,212	30,610	35,496	24,317	11,716	6293
Country-pairs	3956	3406	2958	2704	998	702
Pseudo log-likelihood	−34,920	−24,825	−27,815	−20,266	−6379	−4175
Slope homogeneity test (delta test)		−253.8 (0.0)				

Notes: * Significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. The dependent variable is the number of patents filed in country j by inventors from country i in technology class k in year t. All columns are estimated using a fixed-effects Poisson. All the independent variables are standardized with mean 0 and standard deviation 1. Robust standard errors clustered at country-pair level in parentheses.

Table 8a
Econometric findings, 1995–2007 (period 1), Full sample with each industry separately (GDP current) (without *de facto* IPR measure).

VARIABLES	(1) CCS	(2) insulation	(3) Hybrid-elect	(4) Clean-comb	(5) Fuel-cells	(6) Hydro	(7) Lighting	(8) Solar	(9) HVAC	(10) Wind
Availability$_{ijt-1}$	0.21*	-0.12	0.12	0.10	0.30***	-0.11	-0.02	-0.12	-0.04	-0.19**
	(0.12)	(0.18)	(0.09)	(0.18)	(0.07)	(0.08)	(0.12)	(0.12)	(0.14)	(0.09)
Dejure_IPR$_{jt-1}$	0.28**	0.11	0.88***	0.13	0.63***	0.54***	0.55***	0.91***	0.40***	0.81***
	(0.13)	(0.39)	(0.19)	(0.14)	(0.15)	(0.16)	(0.19)	(0.19)	(0.16)	(0.21)
Defacto_IPR$_{jt-1}$										
Trade_openness$_{jt-1}$	-0.21***	-0.20**	-0.48***	-0.19***	-0.20**	-0.36***	-0.36***	-0.42***	-0.28***	-0.23***
	(0.06)	(0.10)	(0.15)	(0.07)	(0.09)	(0.07)	(0.11)	(0.09)	(0.08)	(0.08)
FDI_openness$_{jt-1}$	0.35**	0.44*	0.41**	0.49***	0.21**	0.38***	0.48***	0.30**	0.53***	0.19
	(0.18)	(0.23)	(0.16)	(0.14)	(0.11)	(0.10)	(0.15)	(0.13)	(0.13)	(0.13)
Policy$_{jt-1}$	0.15*	0.05	0.33***	-0.01	0.38***	0.27***	0.14	0.13*	0.12	0.37***
	(0.08)	(0.12)	(0.12)	(0.07)	(0.09)	(0.08)	(0.14)	(0.08)	(0.08)	(0.09)
I$_{kjt-1}$	0.09***	0.12***	0.04	0.20***	0.08**	0.26***	0.10***	0.13**	0.08**	0.19***
	(0.03)	(0.04)	(0.03)	(0.06)	(0.04)	(0.06)	(0.04)	(0.06)	(0.04)	(0.03)
GDP$_{jt-1}$	0.20	0.44**	0.56***	0.44**	0.20	1.03***	0.96***	0.89***	0.60***	1.45***
	(0.19)	(0.18)	(0.15)	(0.21)	(0.20)	(0.15)	(0.20)	(0.29)	(0.12)	(0.12)
Observations	4,345	1,476	4,379	5,468	5,336	5,293	3,873	6,690	4,629	5,723
Country-pairs	365	123	367	459	448	444	324	560	387	479
Pseudo log-likelihood	-2902	-799.2	-3881	-3762	-4490	-2833	-3032	-5265	-3022	-3993
Wald Test (F test) (for dejure_IPR)	4.61	0.08	20.39	0.88	18.6	11.9	8.36	22.88	6.66	15.1
	(0.03)	(0.77)	(0.0)	(0.35)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)

Notes: * Significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. The dependent variable is the number of patents filed in country j by inventors from country i in technology class k in year t. All columns are estimated using a fixed-effects Poisson. All the independent variables are standardized with mean 0 and standard deviation 1. Robust standard errors clustered at country-pair level in parentheses. The last row gives the Wald test (F-test) results for the null that the coefficient of dejure_IPR variable is zero. Shaded cells in the last row indicate that coefficient of dejure_IPR is not statistically different from zero.

Table 8b
Econometric findings, 1995–2007 (Period 1), Full sample with each industry separately (GDP current) (with *de facto* IPR measure).

VARIABLES	(1) CCS	(2) insulation	(3) Hybrid-elect	(4) Clean-comb	(5) Fuel-cells	(6) Hydro	(7) Lighting	(8) Solar	(9) HVAC	(10) Wind
Availability$_{ijt-1}$	0.15	0.06	0.07	0.16	0.27***	-0.17*	-0.19**	-0.37**	-0.14	-0.19**
	(0.13)	(0.28)	(0.10)	(0.18)	(0.06)	(0.09)	(0.09)	(0.15)	(0.15)	(0.09)
Dejure_IPR$_{jt-1}$	0.05	-0.88	0.65***	0.05	0.33**	0.61***	0.41**	1.34***	0.28	0.61**
	(0.15)	(0.64)	(0.14)	(0.18)	(0.14)	(0.23)	(0.20)	(0.25)	(0.24)	(0.29)
Defacto_IPR$_{jt-1}$	0.28	0.48	0.87***	0.72***	0.85***	-0.38	1.12***	0.30	0.75**	0.79**
	(0.19)	(0.63)	(0.32)	(0.25)	(0.29)	(0.28)	(0.37)	(0.30)	(0.33)	(0.32)
Trade_openness$_{jt-1}$	-0.36***	-0.38***	-0.53***	-0.34***	-0.20***	-0.55***	-0.41***	-0.48***	-0.45***	-0.37***
	(0.04)	(0.12)	(0.09)	(0.07)	(0.06)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
FDI_openness$_{jt-1}$	0.60***	0.61**	0.46***	0.61***	0.23**	0.64***	0.59***	0.40***	0.71***	0.30***
	(0.16)	(0.26)	(0.12)	(0.12)	(0.10)	(0.10)	(0.13)	(0.12)	(0.10)	(0.11)
Policy$_{jt-1}$	-0.05	-0.01	0.15	-0.16*	0.18*	0.07	0.06	-0.08	0.00	0.03
	(0.08)	(0.18)	(0.10)	(0.09)	(0.09)	(0.09)	(0.14)	(0.09)	(0.09)	(0.09)
I$_{kjt-1}$	0.04*	0.08	0.02	0.17***	0.10***	0.20***	0.10***	0.12***	0.06*	0.16***
	(0.02)	(0.06)	(0.02)	(0.06)	(0.03)	(0.05)	(0.04)	(0.04)	(0.03)	(0.03)
GDP$_{jt-1}$	0.48**	0.39	0.84***	0.53**	0.17	1.22***	1.44***	1.42***	0.96***	1.66***
	(0.20)	(0.26)	(0.24)	(0.23)	(0.22)	(0.18)	(0.23)	(0.42)	(0.16)	(0.16)
Observations	2,694	1,008	2,897	3,438	3,639	3,410	2,592	4,123	2,979	3,830
Country-pairs	300	112	322	382	405	380	288	460	331	426
Pseudo log-likelihood	-2013	-556.4	-2781	-2536	-3341	-2043	-2133	-3698	-2109	-3066
Wald Test (F test) for dejure_IPR	0.11 (0.74)	1.89 (0.17)	20.85 (0.0)	0.09 (0.77)	5.67 (0.02)	7.02 (0.0)	4.16 (0.04)	28.79 (0.0)	1.39 (0.24)	4.37 (0.04)
Wald Test (F test) for defacto_IPR	2.16 (0.14)	0.58 (0.45)	7.31 (0.0)	8.4 (0.0)	8.4 (0.0)	1.89 (0.17)	9.13 (0.0)	1.01 (0.31)	5.16 (0.02)	6.16 (0.01)

Notes: *, **, *** indicate significant at the 10 %, 5 % and 1 % level respectively. The dependent variable is the number of patents filed in country j by inventors from country i in technology class k in year t. All columns are estimated using a fixed-effects Poisson. All the independent variables are standardized with mean 0 and standard deviation 1. Robust standard errors clustered at country-pair level in parentheses. The last two rows give the Wald test (F-test) results for the null that the coefficient of dejure_IPR and defacto_IPR variables is zero. Shaded cells in the last row indicate that coefficient of dejure_IPR or defacto_IPR is not statistically different from zero.

differences emerge for the two groups. The stock of knowledge in OECD countries is a key determining factor for technology transfer unlike for non-OECD countries. For non-OECD countries, only *de jure* IPR results in greater technology transfer. The coefficient of *de jure* IPR for non-OECD is larger than that for OECD countries suggesting that in absence of *de facto* IPR in countries, the coefficient on *de jure* IPR is underestimated (as we would expect with measurement error). Similarly, more technology is transferred to non-OECD countries when existing pool of technology to be transferred is higher. Interestingly, openness to FDI in non-OECD countries is associated with a smaller volume of technology transferred and also less technology is transferred to larger countries.

Empirically, the crucial difference between the groups of countries is the relationship between *de jure* and *de facto* IPR. In the innovative OECD countries (North), this relationship is complementary as enforcement actually supports the impact of *de jure* IPR, but in the non-innovative South this is not the case (Jandhyala, 2015).

Table 9
Econometric findings, 2008–2018 (period 2), Full sample with countries divided based on OECD membership.

	Full sample		OECD countries		Non-OECD countries	
Variables	(1)	(2)	(3)	(4)	(5)	(6)
$Availability_{ijt-1}$	−0.05**	−0.06**	0.05**	0.038	1.45***	2.18***
	(0.03)	(0.02)	(0.02)	(0.02)	(0.33)	(0.51)
$Dejure\_IPR_{jt-1}$	0.33***	0.39***	1.50***	1.48***	−0.64***	−0.57***
	(0.12)	(0.12)	(0.10)	(0.10)	(0.08)	(0.08)
$Defacto\_IPR_{jt-1}$		−0.66***		−0.29***		−1.26***
		(0.10)		(0.07)		(0.28)
$Trade\_openness_{jt-1}$	−0.34***	−0.32***	−0.44***	−0.46***	−0.36***	−0.19**
	(0.06)	(0.06)	(0.08)	(0.08)	(0.08)	(0.07)
$FDI\_openness_{jt-1}$	−0.16***	−0.12***	−0.116***	−0.09***	−0.49***	−0.83***
	(0.04)	(0.04)	(0.03)	(0.03)	(0.09)	(0.11)
$Policy_{jt-1}$	−0.14	−0.12	−1.16***	−1.14***	−0.37***	−0.22
	(0.12)	(0.13)	(0.17)	(0.17)	(0.13)	(0.15)
I_{kjt-1}	0.10***	0.09***	0.08***	0.07***	0.07**	0.06**
	(0.01)	(0.02)	(0.01)	(0.01)	(0.03)	(0.03)
GDP_{jt-1}	−0.31***	−0.15*	−0.62***	−0.51***	0.43**	0.73***
	(0.08)	(0.09)	(0.09)	(0.09)	(0.17)	(0.19)
Observations	36,016	33,280	22,344	22,248	13,672	11,032
Country-pairs	4502	4160	2793	2781	1709	1379
Pseudo log-likelihood	−32,521	−31,184	−21,302	−21,227	−9318	−8107
Slope homogeneity Test (delta test)		−260.3 (0.0)				

Notes: *, **, *** indicate significant at the 10%, 5% and 1% level respectively. The dependent variable is the number of patents filed in country j by inventors from country i in technology class k in year t. All columns are estimated using a fixed-effects Poisson. All the independent variables are standardized with mean 0 and standard deviation 1. Robust standard errors clustered at country-pair level in parentheses.

5.6.3. Do post 2008 changes matter?

As argued earlier, different global events including the 2008 financial crises and policy changes post the Copenhagen summit, which may have reduced the demand for international CCMTs. In this context it is worth investigating if the DGM (2013) results on the positive role of IPRs still hold good in the later period of 2008–2018. In order to ascertain whether the later period is different from the earlier 1995–2007 period we conducted tests of structural break both with and without *de facto IPR*. In both cases, the test confirmed the existence of a structural break, with 2008–2018 showing a different pattern of results from 1995 to 2007.[10]

Tables 9, 10a and 10b report results for the later period. Table 9 reports the combined CCMT analysis without *de facto* IPR (in column 1) and with *de facto* IPR (in column 2). Combined CCMT estimation without and with *de facto* IPR for OECD countries is reported in columns 3 and 4 while the estimation for non-OECD countries is reported in columns 5 and 6. As before, we also report separate technology class estimations – without *de facto* IPR (in Table 10a) and with *de facto* IPR variable in (Table 10b).

For the 2008–2018 period, two key results are different for the full sample: the size of the economy (GDP), and openness to FDI are both associated with lower technology transferred. These results hold even with inclusion of *de facto* IPR, where stricter enforcement reduces the number of patents transferred across both groups of countries.[11] As we noted in the discussion of the DGM (2013) model in Section 2.1, a shrinking of the market would give rise to smaller FDI flows even in the presence of liberal FDI polices as FDI would become unprofitable. This result on FDI is reflected in both the OECD and non-OECD samples.

The different signs on the GDP coefficient in OECD and non-OECD countries require some comment. In non-OECD countries we find larger market size (proxied by GDP) is associated with a higher volume of technology transfer as the DGM (2013) model also predicts. But in the OECD group of countries smaller countries attract more technology transfer. This may reflect the fact that larger countries opted for a lower level of emissions control than in the pre-2008 period (see discussion in Section 2.1). The finding may also reflect the effect of emerging patterns of specialization in technologies as some CCMTs matured (see Table 11). Table 11 shows that larger countries are less specialized than smaller countries (*e.g.*, Denmark highly specialized in Wind technologies, Taiwan and Korea in Solar, Japan in Hydro and Electric Vehicles) and consequently smaller countries may be more dependent on inward technology flows through trade and FDI for complementary expertise.

De jure and *de facto* IPRs also play different roles in inducing technology transfer in the two groups of countries. As we noted in the discussion of the DGM (2013) model, the comparative statics leave the effect of IPR on technology transfer ambiguous. A positive effect emerges only if the $p_T < p_I$ and the patent intensity of FDI is higher than that of trade. In the OECD group of countries the effect of *de jure* IPR is positive while the effect of *de facto* IPR is negative. As these are coefficients of standardized variables, we can also see that the positive effect of the *de jure* coefficient outweighs the negative effect of the *de facto* coefficient. For non-OECD countries stronger *de jure* IPR and *de facto* IPR is associated with a lower volume of technology transfer. The declining role of *de jure* and *de facto* IPR in non-OECD countries may reflect that in the changed regime firms are wary of IPR or that IPR rules may be less important than other policies such as bilateral investment treaties, TRIPS plus provisions and climate finance agreements, which became more frequent after 2008 (Athreye et al., 2020). In our estimations these factors are picked up only in the country pair fixed effects of the estimated model.

Lastly, we see the impact of stronger IPRs on technology transfer in each technology class separately for 2008–2018. Interestingly, and as conjectured in Section 2.1, we do not find any role of *de jure* IPR on technology transferred – whether we include it as standalone IPR measure or along with *de facto* IPR measure. The Wald test (reported in the last row of Table 10a and second last row of Table 10b) also suggest that the coefficient on *de jure* IPR is not statistically different from zero and could thus be dropped from the equation. The coefficient on *de facto* IPR

[10] For estimations without the *de facto IPR*, the test statistic was $\chi2$ (8) = 556.64, Prob > $\chi2$ = 0.0000. For estimations with *de facto IPR*, the test statistic was $\chi2$ (9) = 425.81, Prob > $\chi2$ = 0.0000. These results are also reported in the supplementary tables.

[11] To explore the *de facto* IPR results further, we used the three disaggregated components of *De facto_IPR*, namely costs of servicing, costs on account of poor property protection and monitoring (litigation) costs and estimated their impact on technology transfer. Our estimation reveals that lower transaction costs due to better servicing and administrative quality had a positive influence on the number of technologies transferred. However, stronger property protection and litigation that goes in favour of the patent holder almost always results in a lower number of patents transferred—possibly because successful litigation strengthens the monopoly power of the inventor. Results are available on request.

Table 10a
Econometric findings, 2008–2018 (period 2), Full sample with each industry separately (without *de facto*).

VARIABLES	(1) CCS	(2) Insulation	(3) Hybrid-elect	(4) Clean-comb	(5) Fuel-cells	(6) Hydro	(7) Lighting	(8) Solar	(9) HVAC	(10) Wind
$Availability_{ijt-1}$	-0.06	-0.26**	0.00	0.18	-0.24	-0.42***	-0.31**	-0.18**	-0.18	-0.11
	(0.18)	(0.13)	(0.07)	(0.17)	(0.29)	(0.07)	(0.13)	(0.08)	(0.20)	(0.09)
$Dejure\_IPR_{jt-1}$	-0.07	-0.17	0.48	0.22	0.05	-0.21	0.46	0.58	0.10	0.24
	(0.25)	(0.39)	(0.41)	(0.19)	(0.25)	(0.15)	(0.44)	(0.38)	(0.32)	(0.19)
$Defacto\_IPR_{jt-1}$										
$Trade\_openness_{jt-1}$	-0.32**	-0.87***	-0.26**	-0.47***	-0.39***	-0.56***	-0.46***	-0.17	-0.26*	-0.35**
	(0.13)	(0.29)	(0.12)	(0.14)	(0.11)	(0.12)	(0.17)	(0.14)	(0.14)	(0.16)
$FDI\_openness_{jt-1}$	-0.19	-0.28	-0.20**	-0.03	-0.22**	-0.14*	-0.07	-0.18**	-0.18*	-0.12
	(0.13)	(0.18)	(0.10)	(0.11)	(0.09)	(0.07)	(0.13)	(0.10)	(0.10)	(0.10)
$Policy_{jt-1}$	-0.61***	-0.52	0.11	-0.03	0.01	-0.37	-0.01	-0.13	-1.30***	0.19
	(0.23)	(0.88)	(0.28)	(0.26)	(0.41)	(0.36)	(0.43)	(0.25)	(0.37)	(0.30)
I_{kjt-1}	0.26***	0.09*	0.15***	0.22***	0.05	0.1 l**	-0.03	0.21***	-0.01	0.17***
	(0.06)	(0.05)	(0.03)	(0.03)	(0.08)	(0.05)	(0.05)	(0.06)	(0.03)	(0.04)
GDP_{jt-1}	-0.28	0.13	-0.28	-0.89***	-0.16	-0.14	0.09	-0.08	-0.13	-0.60***
	(0.35)	(0.38)	(0.23)	(0.27)	(0.30)	(0.19)	(0.26)	(0.22)	(0.29)	(0.20)
Observations	3,184	992	3,504	3,592	3,744	4,344	2,440	5,896	3,008	5,312
Number of Country-pairs	398	124	438	449	468	543	305	737	376	664
Pseudo log-likelihood	-2341	-536.1	-4591	-2661	-3460	-2932	-1983	-6346	-2072	-5192
Wald Test (F test) (for dejure_IPR)	0.07 (0.79)	0.19 (0.66	1.35 (0.24	1.37 (0.24)	0.04 (0.84)	2.04 (0.15	1.08 (0.3)	2.31 (0.13)	0.10 (0.75)	1.59 (0.21)

Notes: * Significant at the 10 % level, ** significant at 5 % level, *** significant at 1 % level. The dependent variable is the number of patents filed in country j by inventors from country i in technology class k in year t. All columns are estimated using a fixed-effects Poisson. All the independent variables are standardized with mean 0 and standard deviation 1. Robust standard errors clustered at country-pair level in parentheses. The last row gives the Wald test (F-test) results for the null that the coefficient of dejure_IPR variable is zero. Shaded cells in the last row indicate that coefficient of dejure_IPR is not statistically different from zero.

Table 10b
Econometric findings, 2008–2018 (Period 2), Full sample with each industry separately (with *de facto*).

VARIABLES		(1) CCS	(2) Insulation	(3) Hybrid-elect	(4) Clean-comb	(5) Fuel-cells	(6) Hydro	(7) Lighting	(8) Solar	(9) HVAC	(10) Wind
$Availability_{ijt-1}$		-0.20	-0.31**	-0.00	0.04	-0.39	-0.41***	-0.35***	-0.22***	-0.24	-0.13
		(0.20)	(0.13)	(0.08)	(0.19)	(0.30)	(0.07)	(0.13)	(0.08)	(0.19)	(0.10)
$Dejure\_IPR_{jt-1}$		-0.04	-0.11	0.53	0.23	0.08	-0.10	0.50	0.57	0.13	0.26
		(0.24)	(0.38)	(0.40)	(0.18)	(0.24)	(0.16)	(0.43)	(0.37)	(0.31)	(0.20)
$Defacto\_IPR_{jt-1}$		-1.04***	-1.20**	-0.83***	-0.86***	-0.84***	-0.14	-1.10***	-0.77***	-0.64**	-0.13
		(0.31)	(0.49)	(0.27)	(0.29)	(0.24)	(0.28)	(0.26)	(0.19)	(0.27)	(0.31)
$Trade\_openness_{jt-1}$		-0.28**	-0.85***	-0.21	-0.44***	-0.37***	-0.49***	-0.41***	-0.19	-0.23	-0.34**
		(0.13)	(0.31)	(0.13)	(0.14)	(0.11)	(0.12)	(0.15)	(0.15)	(0.15)	(0.16)
$FDI\_openness_{jt-1}$		-0.16	-0.20	-0.14	-0.03	-0.19**	-0.16*	0.04	-0.16**	-0.14	-0.14
		(0.14)	(0.18)	(0.09)	(0.12)	(0.09)	(0.08)	(0.12)	(0.08)	(0.10)	(0.11)
$Policy_{jt-1}$		-0.57***	-0.10	0.21	-0.01	-0.01	-0.54	-0.02	-0.07	-1.45***	0.14
		(0.19)	(1.02)	(0.30)	(0.26)	(0.43)	(0.36)	(0.46)	(0.24)	(0.51)	(0.39)
I_{kjt-1}		0.22***	0.10*	0.13***	0.19***	0.06	0.11**	-0.04	0.19***	-0.02	0.18***
		(0.06)	(0.05)	(0.03)	(0.03)	(0.08)	(0.05)	(0.04)	(0.05)	(0.03)	(0.04)
GDP_{jt-1}		0.24	0.47	-0.07	-0.49	0.15	-0.12	0.35	0.16	0.08	-0.55**
		(0.44)	(0.44)	(0.30)	(0.34)	(0.34)	(0.21)	(0.30)	(0.22)	(0.28)	(0.22)
Observations		2,984	984	3,352	3,304	3,512	3,864	2,328	5,288	2,816	4,848
Country-pairs		373	123	419	413	439	483	291	661	352	606
Pseudo log-likelihood		-2246	-531.1	-4480	-2549	-3346	-2749	-1928	-5967	-2005	-4943
Wald Test (F test) for	dejure_IPR	0.03 (0.8	0.08 (0.78	1.82 (0.18)	1.59 (0.21	0.11 (0.74)	0.45 (0.50)	1.38 (0.24)	2.34 (0.13)	0.18 (0.67)	1.79 (0.18)
	defacto_IPR	11.19 (0.0)	6.06 (0.01)	9.39 (0.0)	8.83 (0.0)	12.05 (0.0)	0.26 (0.61)	18.79 (0.0)	15.94 (0.0)	5.66 (0.017)	0.18 (0.67)

Notes: * Significant at the 10 % level, ** significant at the 5 % level, *** significant at the 1 % level. The dependent variable is the number of patents filed in country j by inventors from country i in year t. All columns are estimated using a fixed-effects Poisson. All the independent variables are standardized with mean 0 and standard deviation 1. Robust standard errors clustered at country-pair level in parentheses. The last two rows give the Wald test (F-test) results for the null that the coefficient of dejure_IPR and defacto_IPR variables is zero. Shaded cells in the last row indicate that coefficient of dejure_IPR or defacto_IPR is not statistically different from zero.

is negatively significant for eight of the total 10 technology classes. The Wald test justifies the inclusion of *de facto* IPR (last row, Table 10b). The available inventions for potential transfer (I_{kjt-1}) is associated with more technology transfer through patenting activity in the recipient country, except in the case of fuel-cells, lighting and HVAC technologies. Openness to trade and FDI, wherever they are statistically significant, in the recipient country is associated with a lower volume of technology transferred — a finding consistent with the disruptions to international trade and FDI due to the financial crisis and reduced demand for international mitigation technologies due to the lower level of commitments pledged in the Copenhagen accord.

5.7. Robustness of results

Although we were constrained by the requirements of the replication, wherever possible we experimented with alternative measures of variables in order to check the robustness of the results.[12] We report on these below:

[12] We are very grateful to comments by two anonymous referees for suggesting several of these checks. All results have been presented in Supplementary tables to the Editors, and are also available from the authors on request.

Table 11
Specialization of the top 15 CCMT originating countries (% shares).

Country	Biofuels	CCS	Clean combustion	Fuel cells/hydrogen	Geothermal	HVAC	Hybrid and electric	Hydro	Insulation	Lighting	Nuclear	Solar	Wind	Total
Japan	4.8	2.8	3.6	14.7	0.2	4.6	36.1	1.1	0.4	4.9	2.5	21.5	2.9	100
US	16.8	7.9	8.7	11.8	0.5	3.8	13.8	2.3	0.7	4.6	8.7	14.6	5.9	100
Germany	8.6	4.4	5.8	9.4	0.5	3.9	15.5	2.2	1.1	4.5	4.8	20.0	19.3	100
France	9.8	6.7	6.0	10.3	0.4	6.2	14.2	4.7	0.9	1.5	19.9	15.4	4.1	100
Korea, rep of	4.6	2.3	1.7	16.2	0.2	5.9	24.2	1.6	0.3	6.8	2.8	30.7	2.7	100
The UK	10.6	6.8	8.4	11.1	0.8	4.6	8.8	10.6	0.5	4.0	5.4	16.8	11.6	100
Canada	19.0	6.0	5.1	16.4	1.4	5.5	10.0	6.1	0.6	4.3	3.6	14.9	7.1	100
Taiwan	2.5	0.8	1.0	7.6	1.1	2.7	10.4	3.2	0.2	22.9	0.2	39.9	7.5	100
The Netherlands	20.5	7.8	3.8	6.2	0.5	5.5	3.9	2.9	0.6	22.7	1.1	14.3	10.2	100
Denmark	18.3	1.9	4.2	5.2	0.1	4.6	0.7	2.6	0.2	0.7	0.1	3.5	57.9	100
Italy	15.3	3.5	6.9	12.6	0.3	7.8	11.1	3.8	0.5	5.1	4.6	17.6	10.9	100
China	8.7	2.1	2.8	6.6	0.7	4.6	13.8	3.5	0.8	17.8	2.7	24.9	10.9	100
Switzerland	10.4	2.9	16.5	7.3	2.0	6.8	11.2	5.6	0.7	3.8	2.5	26.4	3.9	100
Sweden	12.8	3.5	9.6	2.4	2.5	8.7	17.0	8.1	0.0	1.8	15.6	10.6	7.4	100
Australia	17.1	5.6	5.4	9.8	0.5	4.7	6.4	10.0	1.8	3.3	0.6	27.7	6.9	100

Note: Shaded cells represent the top two focus technologies by each country.
Source: Our re-elaboration on PATSTAT Online, Autumn 2018 edition data.

(i) Exchange rate movements and technology transfer: To better account for the role of exchange rate movements, we used GDP PPP instead of GDP current prices, but this had no effect on the results. Our estimations are reported in the supplementary tables and also available on request.

(ii) Alternative measures of environmental policy: The count variable for climate policy measures enactment rather than stringency of climate policy (similarly to *de jure* IPR). The Environmental Policy Stringency (EPS) Index developed by OECD is a proxy of the stringency of 14 climate change policy instruments, where stringency is defined as the degree to which the emission of greenhouse gases or behaviors harmful to the environment are implicitly or explicitly sanctioned. The index ranges from 0 (not stringent at all) to 6 (highly stringent). It is available for fewer countries (approximately half the sample), and we could not use it here as it would have thrown out most of the non-OECD observations. Nevertheless, the results of this alternative estimation suggest that the stringency of climate policies in the host countries is positively associated with the incoming flow of foreign patents. The estimated coefficients of EPS_{jt} were positive and statistically significant (at 1 % level) both in the model where the technologies are pooled together and in models where technology classes are estimated separately. Please see details in Martelli (2019).

(iii) Linear interpretation of the Ginarte and Park patent index between 5-year periods might forces a linearity which in turn dominates the *de jure* calculations. Although our choices on this were shaped by the requirements of replication, as a robustness check we also estimated the model in first differences (FD) rather than using fixed effects (FE). These results are reported in the supplementary tables. The FD estimates drop a large number of observations and in addition show the opposite results to the original DGM (2013) paper, but it is hard to conclude much from this as we do not know if the change in sign is due to the changed sample.

In panel estimations when $T > 2$, FD estimates are preferred when there is suspected auto-correlation of errors. As we have used clustered errors this is highly unlikely. When errors are uncorrelated and $T > 2$, FE estimations produce more efficient estimators. Furthermore, apart from DGM (2013), other authors such as Kanwar (2012) using different measures of technology transfer confirm the positive role played by IPRs in promoting technology transfer in the immediate aftermath of TRIPS.

(iv) The reduction in patent applications at the end of the period (Fig. 1) may simply be the result of truncation of patents reported, associated with lags in reporting. This is a common problem in patent analysis and to address it we re-estimated Table 9 with a shorter time frame (through 2015 instead of 2018) to see if the negative results on non-OECD IP policies are robust. The sign and significance level of our key variables (*de jure* and *de facto* IPR) for non-OECD countries remains the same even with the reduced sample.

6. Summary and implications

Early studies have given a central role to strengthening of IPRs as the mechanism for international technology transfer of CCMTs. This central role accorded to IP protection in the international transfer of CCMTs is at odds with both the literature on the effect of IPRs on technology transfer to developing countries and the history of TRIPS resistance and eventual acceptance by many non-OECD countries. Furthermore, while TRIPS led to an expansion of technology trade at the extensive margin (due to expanded coverage of patentable sectors) there is little evidence that it gave rise to expanded technology trade within particular sectors (Verdolini and Bosetti, 2017). Furthermore, as globalisation receded and the international governance of climate moved from mandated to voluntary control of emissions, it is likely that global markets for CCMTs shrank and the role played by IPRs in technology transfer also changed. In policy forums developing countries (especially India) have put forth ideas and plans to ensure that IPRs do not become a barrier on the diffusion of climate friendly technologies (Krishna, 2009). These include the setting up of multilateral funds to buy IPRs for CCMTs and make them freely available.

Recognising this, we felt it important to further explore the role of IPRs taking into account a recent time period (2008–2018), the heterogeneity among countries (OECD *versus* non-OECD), and a better measure of the enforcement costs of patenting, which measure the stringency of patent protection. Our paper is a quasi-replication of the well-accepted DGM (2013) study showing the role of IPRs in fostering the cross-border transfer of CCMTs in the 1995–2007 period (*i.e.*, immediately after TRIPS). Our replication exercise finds that technology transfer to non-OECD countries is associated with a different set of policies compared to OECD countries. We also find that strong IP policies have not had the same beneficial CCMTs transfer outcomes in 2008–2018 as they did in the earlier period, and in fact strong *de facto* IPR reduced the volume of CCMTs transfer to all countries.

In sum, our replication does cast doubt on a central conclusion of the DGM (2013) paper written at a time of more optimistic global environment. The authors conclude that:

> "*[...] relaxing IPR for green technologies, as advocated by certain developing countries, could be detrimental to the international diffusion of technological knowledge. This claim is reinforced by the fact that, if IPR is weakened, it prompts innovators to rely on secrecy to protect their inventions, which would negatively impact the international diffusion of knowledge because secret inventions diffuse less extensively in the recipient economy. Similarly, raising barriers to trade or to FDI also could be detrimental to international technology diffusion, although the impact may not be as strong*"
>
> (DGM 2013, p.176)

Our empirical results give voice to the protests by developing countries that IPRs are not helping gain access to CCMTs, though we would add that this is also because the globalisation and the governance of climate change has made IPRs more redundant now than it was before. In the short term, national policy makers can rely on a number of alternative measures that lower the barriers posed by IPRs. These include: the regulation of voluntary licenses, the exercise by governments of their right to provide compulsory licenses, and other TRIPS Agreement-related flexibilities (such as parallel importation, exemptions to patentability, exceptions to patent rights, and measures to address anti-competitive behaviour) – all of which can be used to promote the international transfer and diffusion of CCMTs (Kohr, 2012). Despite the existence of these provisions, they are underutilised, and more may be achieved by strengthening these provisions than IPRs alone.

However, a limitation of our study is that as we chose to do a quasi-replication, we are unable to say more about the policies that would promote transfer of CCMTs in the changed regime since 2008. This would require modelling of a different governance world where financial flows and bilateral agreements may matter as much, if not more, than IPR policy. That is beyond the scope of the original DGM study and our quasi-replication, but we hope our paper has cast the first stone in that direction of study.

CRediT authorship contribution statement

Suma Athreye participated in the drafting and directed the analysis of the data.

Vinish Kathuria provided specialist econometric support and participated in the drafting of the paper.

Lucia Piscitello participated in the drafting and directed the analysis of the data.

Alessandro Martinelli compiled the data and conducted the empirical analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Derivation of the empirical model—based on the exposition in DGM, 2013

To characterize the mechanisms underlying technology transfer, DGM (2013) develop a model that they use to derive predictions, which they then test empirically. The model features a set of firms that decide whether to transfer a technology into a foreign country and what transfer channel (trade or FDI) to use.

Assuming there are *Ki* heterogeneous firms in country *i*. Each has developed an innovative technology they seek to commercialize in another country *j*. The technology can serve a market of size θ *j* in country *j*, which is drawn from a distribution *Fj* on the interval $[0, \theta_j^{max}]$.

To simplify notations, they ignore the subscripts *i* and *j* in the later exposition.

Innovative technology is defined as an information set {*a, b*} where *a* and *b* denote, respectively, a product invention and the related production process; both of which are patentable. If the firm with the technology of type θ decides to enter country *j*, it can choose between two channels: (1) manufacturing the innovative product at home and exporting it into country *j*; or (2) investing directly in country *j* to set up a local production unit. In the first case, the manufacturing process *b* remains in country *i*, but competitors in country *j* can access the product invention *a* through reverse engineering. In the second case, both the product and manufacturing process are transferred into country *j*. In addition to reverse engineering, local competitors also can access the manufacturing process (*e.g.*, through labor circulation in the local labor market).

Assuming that a firm with type θ decides to enter country *j*, its expected profit is.

$$V_\gamma(\theta) = p_\gamma(ipr)\theta\pi_\gamma - c_\gamma \text{ with } \gamma = I, T \tag{3}$$

where *I* and *T* denote, respectively, the FDI and trade channels for the transfer of technology. The other parameters are the profitability of the foreign market π_γ, a fixed cost of entry c_γ, and $p_\gamma(ipr)$, which is the probability that the technology will not be counterfeited by local competitors. This probability depends on *ipr*, the stringency of patent law in a country, with $ipr \in [0,\infty]$ and $p_\gamma(ipr) \to 1$ when $ipr \to +\infty$. In fact, our paper emphasises that the profitability of entry depends on how well infringements are monitored and the administrative apparatus for doing so—all of which are correct depiction of the costs of patent enforcement, which may differ even when all countries sign up to the same law.

Next DGM introduce two assumptions that aim to capture two key differences between the FDI and trade channels for the transfer of technology. First, they assume that exports entail a lower risk of imitation than FDI and are less responsive to patent strength. Mathematically:

Assumption 1. For any ipr, $p_T(ipr) > p_I(ipr) > 0$; $0 < p_T^{'}(ipr) < p_I^{'}(ipr)$.

The second difference between the FDI and trade channels concerns the costs and benefits of each channel. They assume a higher entry cost if technology transfer takes place through FDI as it requires investing upfront in a new production unit. However, FDI also make it possible to reduce the variable cost of production as exporting goods entails the additional risk of variability in transportation costs, exchange rates, trade tariffs and, in some cases, higher manufacturing costs. Accordingly, they introduce the following assumption:

Assumption 2. The costs and profitability of trade and FDI are such that $c_I > c_T$, $\pi_I > \pi_T$, $\pi_I/c_I > \pi_T/c_T$.

Under these two assumptions, the choice between the FDI and trade channels depends on a trade-off between the lower cost of entry through trade and the economies of scale than can be achieved through FDI if the market is sufficiently large (if θ is high). The last inequality imposes that the trade channel is preferable to the FDI channel if the market is not sufficiently large.

Assumptions 1 and 2 and Eq. (3) predict that the entry strategy of the firm will depend upon θ, which is the market size. Specifically:

Lemma 1. The firm does not transfer the technology if $\theta < \theta_0$. It transfers the technology through trade if $\theta_0 \leq \theta < \theta_1$ and through FDI if $\theta \geq \theta_1$ with the following:

$\theta_0 = c_T/p_T\ (ipr)\pi_T$ and $\theta_1 = c_I - c_T/(p_I\ (ipr)\pi_I - p_T\ (ipr)\pi_T$.

Lemma 1, can also derive the dependent variable $N_{i\,j}$, the number of patent flows from country *i* to country *j*.

Let α and β denote the number of patents filed by a firm when using the trade or the FDI channel, respectively. Because FDI requires transferring both product and process inventions, while trade only requires transferring the former, we have $\alpha < \beta$. Assuming without loss of generality that *ipr* is large enough to have some FDI ($\theta_{max} \geq \theta_1$), it follows that the number of firms choosing each channel is:

- FDI: $K[1 - F(\theta_1)]$.
- Trade: $K[F(\theta_1) - F(\theta_0)]$.
- No entry: $KF(\theta_0)$.

The number of patents filed in country *j* by inventors from country *i* is therefore as follows:

$$Ni\,j = K(\alpha\,F(\theta_1) - F(\theta_0)\,) + (\beta(1 - F(\theta_1)\,)\,)$$

or, after rearranging:

$$Ni\,j = K(\beta - F(\theta_1)(\beta - \alpha) - \alpha\,F(\theta_0)\,) \tag{4}$$

where $F\,(\theta 1)(\beta\ \alpha)$ captures a substitution effect between export and FDI, while $\alpha\,F(\theta_0)$ captures a barrier to entry effect. This expression also makes it possible to derive general predictions about the expected effects of policy variables, such as the strength of patent law in country *j* (*ipr*) or barriers to trade or FDI in country *j* (reflected in c_I and c_T), as follows:

Propositions. The policy variables have the following impact on the aggregate flows of patents from country i to country j:

1. Stronger patent protection in country j increases the incoming flow of patents.
   (The result of differentiating Eq. (4) w.r.t *ipr* and noting that $\alpha - \beta < 0$).
2. Higher barriers to FDI in country j decrease the incoming flow of patents.
   (The result of differentiating Eq. (4) w.r.t c_I and noting that $\alpha - \beta < 0$, so trade substitutes for FDI as policies create barriers for FDI).
3. Higher barriers to trade in country j have an ambiguous effect on the incoming flow of patents.
   As a result of differentiating Eq. (4) w.r.t c_T and noting that $\alpha - \beta < 0$, so barriers to trade reduce technology transfer through exports (less patents are transferred) but may also induces a substitution to FDI (where more patents may be transferred) but the net effect on technology transfer remains ambiguous.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.respol.2023.104819.

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