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Do green foreign direct investments increase the innovative capability of MNE subsidiaries?

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ABSTRACT

Technologies to mitigate climate change may diffuse from lead markets to the rest of the world through several mechanisms and make important contributions to the global green transformation. In this paper, we explore the role played by multinational enterprises (MNEs) in transferring knowledge and innovative capabilities in green technologies to their global subsidiaries. We posit that the degree of green knowledge transfer and innovative capability development in subsidiaries depend on: (i) the host country characteristics, (ii) the specific technology in question, and (iii) the mode of entry. The empirical analysis combines data on foreign direct investments with patent analysis. The results suggest that being a subsidiary of a green MNE has a positive impact on the number and quality of green patents produced locally. This green innovative advantage vis-à-vis domestic companies is larger in less developed countries and in those that are less reliant on oil rents, in particular if they already possess higher levels of relevant domestic innovative capacity. Furthermore, firm and sectoral characteristics also matter. The analysis suggests that green FDIs are more effective when technologies are characterized by low tradability and tacit knowledge. Finally, cross-border acquisitions are more efficient at strengthening green innovative capabilities than subsidiaries established with greenfield investments.

1. Introduction

The international transfer and diffusion of low-carbon technologies have attracted significant scholarly attention and political interest for their essential contribution in mitigating climate change (Iyer et al., 2015; Rempel & Gupta, 2021). The acceleration of green technology transfer is a cornerstone of the United Nations Framework Convention on Climate Change (UNFCCC), which has adopted a range of governance frameworks, such as the Technology Needs Assessments (TNA) and the Climate Technology Centre and Network (CTCN), to fast-track the green transition. Renewable energy (RE) technologies, such as wind and solar photovoltaic (PV), are considered very promising in terms of achieving a low-carbon transition globally in the energy sector (IRENA, 2019). While countries in Europe have previously been the lead markets, the development and diffusion of RE technologies are increasingly taking place on a global scale, including in several latecomer countries (IEA, 2018; IRENA and ADFD, 2020; UNCTAD, 2023).

Accelerating the global diffusion of RE technologies is key to investigating its organization within global value chains (GVC), in which a small number of multinational enterprises (MNEs) play a central role in diffusing the technological hardware and the knowledge necessary to achieve a low-carbon transition in the local economies hosting their subsidiaries. Since these MNEs control the functional division of labor throughout the value chain (Dallas et al., 2019), they can potentially provide their local affiliates with the strategic resources and knowledge needed to engage in innovation in their local markets (Ambos et al., 2021; Lema et al., 2019). Therefore, knowledge transfer within the GVC is an impor-

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tant channel, possibly driving the diffusion of international low-carbon technologies, and overcoming the lack of knowledge and technology, which is often reported as a key barrier to achieving the green energy transition, especially in less developed countries (IRENA, 2017).

As highlighted in a recent report published by the International Panel of Climate Change (IPCC, 2022),[1] the extensive literature on low-carbon technology transfer is a broad and fragmented area of research (see also Kirchherr & Urban, 2018). Generally, much of the literature in this field is focused on specific channels of technology transfer, such as licensing agreements, the trade in (green) goods (Hansen & Nygaard, 2019), cross-border movements of employees and participation in GVCs (Pigato, 2020). Essentially, such channels may function as vehicles for exchanging and transmitting technology in various shapes and forms, such as know-how, hardware components and technical documents, between different actors across borders (Hansen & Lema, 2019). For example, various studies have focused on the importance of the so-called Clean Development Mechanism projects (Lema & Lema, 2016; Gandenberger et al., 2016), while others have investigated patenting activity as an indicator of low-carbon technology transfer and innovation (Dechezleprêtre et al., 2013; Probst et al., 2021).

One subset of research in this field that is particularly relevant for this paper focuses on foreign direct investments (FDIs) undertaken by MNEs as a focal channel of low-carbon technology knowledge transfers and innovation capability-building in the host economies (e.g., Noailly & Ryfisch, 2015; Konara et al., 2021; Castellani et al., 2022). While these contributions are both timely and substantial, research on the importance of FDIs in enhancing green innovation is still limited. Currently, there is only a limited understanding of the role of MNEs in distributing knowledge to their local affiliates, which may enable them to improve their innovative capabilities and engage in developing and deploying green technologies in their local economic systems. With a few important exceptions (Chiarvesio et al. (2015), Melane-Lavado et al. (2018) and De Marchi et al. (2022)), there is almost no evidence available in the literature about how MNEs' subsidiaries with respect to domestic companies can positively spur the development of green innovation in countries at different levels of development. The studies just cited focus either on one country alone or on a set of developed countries (Italy, Spain, and fourteen European countries respectively). This article provides a significant contribution to this literature by examining a larger number of countries, also investigating green foreign direct investments in lower and upper middle-income countries. This enables us to contribute to key academic and policy debates concerning international knowledge transfers in the context of the global green transformation.

To fill this knowledge gap, the present paper explores the following main question: *To what extent are MNEs, through their FDIs* in RE *technologies, contributing to the increase in the green innovative capabilities of their subsidiaries vis-à-vis domestic companies?*

To address this urgent issue empirically, we investigate the following related questions.

- First, *whether and how the degree of knowledge transfer and innovative capability development in subsidiaries depends on host country characteristics?* This is key to accounting for differences among countries at different levels of economic development, with distinct absorptive capacity and diverse degrees of dependence on oil production (Awijen et al., 2022; Noailly & Ryfisch, 2015).
- Second, *whether and how the degree of knowledge transfer and innovative capability development in subsidiaries depend on the specific technology*? In the paper, we investigate differences between solar PV and wind in this context (Binz & Truffer, 2017; Steffen et al., 2018; Quitzow et al., 2017).
- Third, we ask *whether and how the degree of knowledge transfer and innovative capability development in subsidiaries depends on the mode of entry chosen by the MNE*? Here, we distinguish between greenfield investments and acquisitions (Amendolagine et al., 2021a).

In the empirical analysis, we test a negative binomial model on a database of 1,055 green FDIs from 2003 to 2015 and a counterfactual sample of green companies, with at least one patent in RE technologies, which are neither an investor nor a subsidiary. The green investments are distributed across countries at different levels of development, with about one fourth of the subsidiaries located in middle-income host countries according to the World Bank's classification.[2]

We find that MNEs subsidiaries do outperform domestic companies with respect to the number of green patents and their average number of forward citations. Most importantly, there is a larger technological gap between subsidiaries and domestic companies in host middle-income countries than in high-income ones, as well as in countries with better innovative capabilities. In other words, green FDI is a key channel for transferring and developing green knowledge in middle-income countries with good innovative capacity, as exemplified by China and India. Moreover, the benefits of green FDI vary across different renewable energy technologies and are greater in the wind industry, which is characterized by low tradability and tacit knowledge, than in the solar PV sector, which is highly tradable and has explicit knowledge. Lastly, we find that cross-border acquisitions have a greater impact on the subsidiaries' green innovative capacity than greenfield investments because they can take advantage of a wider pool of knowledge and technological resources and can combine their own and those acquired within the corporate network. These findings make key contributions to the specific literature on subsidiary innovative capacity in green technology and its sectoral variations, as well as more broadly to key debates about international technology transfers in green technology.

The remainder of this paper is organized as follows. In the next section we discuss the existing literature on these phenomena, and in Section 3 we introduce the methodology and the database. Section 4 then presents and discusses the empirical results on the whole sample and two different sub-samples to account for differences in technologies and modes of entry. Section 5 concludes by discussing the policy implications of our findings.

2. Green FDI and innovation

Given the limited research on FDI as a channel for low-carbon technology transfer, there is a need to take some exploratory steps in order to develop a conceptual framework to guide the empirical analysis. As an overarching source of inspiration, we draw on the literature on knowledge transfer in MNEs' relations with their subsidiaries (Ambos & Ambos, 2009; Björkman et al., 2004; Minbaeva, 2007; Mudambi et al., 2017; Perri & Peruffo, 2016), mainly on previous research on low-carbon technology transfers through FDI (e.g., Noailly & Ryfisch, 2015; Konara et al., 2021; Castellani et al., 2022). Insights from different strands of the literature are combined to guide the empirical tests of the extent to which MNEs

[1] Specifically, see Section 16 on 'Innovation, technology development and transfer'.

[2] The income classification of host countries is based on World Bank country groups.

through FDIs increase the quantity and quality of innovations in RE technologies undertaken by their subsidiaries vis-à-vis domestic companies.

In the 1980s and 1990s, an influential body of literature emerged stating, that while parent firms often distributed their innovative solutions across international borders, they tended to restrain the diffusion of the underlying knowledge (Lall, 1993). Subsequently, it was found that, while some market-seeking investments followed the earlier pattern, a new wave of resource- and knowledge-seeking investments started to change the picture. In fact, MNEs sometimes transfer technology globally through investment-centered value chains as they seek to exploit knowledge in foreign subsidiaries as part of a broader trend towards the internationalization of R&D (Perri & Peruffo, 2016; Ambos et al., 2021).

In the specific case of green technologies, Noailly and Ryfisch (2015) assess the internationalization of R&D by studying the patenting activity of 1,200 MNEs and find that their affiliates develop around 18 per cent of their patents. Based on innovation survey data for MNE subsidiaries in Spain, Konara et al. (2021) find that affiliates with parent MNEs from countries with stricter environmental policies engage in environmental innovations to a greater extent. In the Italian case, and using survey data, Chiarvesio et al. (2015) study environmental innovations in a sample of 684 firms across various sectors and find that affiliation with MNEs enhances their propensity to engage in innovative activity. Investigating fourteen European countries with data from the Community Innovation Survey (CIS), De Marchi et al. (2022) show that MNEs' affiliates display superior performance in green innovation than domestic companies. Finally, adopting a regional perspective, Castellani et al. (2022) reveal that in Europe greenfield FDIs contribute to regional specialization in environmental technologies, especially in industries with previous capabilities in specific green technologies.

In the present paper, we suggest that the effect of green FDI on the subsidiaries' innovative capabilities is mediated by different sets of determinants: at the host-country level described in Section 2.2; at the level of the investing company, accounting for sector-specificity, illustrated in Section 2.3; and for mode of entry, Section 2.4. Fig. 1 presents the conceptual framework tested with the empirical analysis presented in Section 4. We posit that MNEs' subsidiaries, resulting from green FDIs, are more innovative in RE technologies than domestic companies and that their technological advantage is mediated by the host-country characteristics (level of development, degree of innovativeness, dependence on oil rents) and firm-related factors (technological sector, FDI entry mode).

2.1. Host-country characteristics

We consider three host-country characteristics: the level of development, the absorptive capacity, and the dependence on oil. Based on the existing literature, in what follows we elaborate our expectation with respect to the three determinants included in the empirical analysis.

The technological gap between MNE subsidiaries and domestic companies depends on the host country's overall level of development. We expect domestic companies in middle-income countries to suffer to a greater extent from the *liability of localness* in producing innovation (Un, 2011, 2016). With respect to domestic companies located in high-income countries, those in middle-income countries have fewer opportunities to connect to global innovation networks and employ multicultural employees, who may facilitate the integration of new knowledge and the production of new technologies.

At the same time, recent case studies of the subsidiaries of high-income countries' MNEs based in developing economies and operating in the wind and solar sectors offer an illustration of how innovative capabilities may be improved in the case of FDIs (Hansen et al., 2020; Davy et al., 2021). For instance, using the example of an Indian subsidiary of a Danish first-tier supplier of wind-turbine blades, Hansen et al. (2020) show that, although initially the subsidiary only had basic innovative capabilities, over time it has developed more advanced capabilities, complementary to those of the parent company, driven by the need to adapt new technologies to different local physical conditions (i.e., weather and soil characteristics). Similarly, Davy et al. (2021) show that the development of advanced innovation capabilities in a local subsidiary operating in the solar power sector in South Africa depend critically upon its 'dual embeddedness' in both the local innovation system and its access to knowledge from its parent company.

The literature on knowledge transfers in MNE subsidiaries and the broader development literature on spillovers from FDI are widely concerned with absorptive capacity (Blomström & Sjöholm, 1999; Saggi, 2002). Essentially, absorptive capacity involves the ability of actors to assimilate and effectively utilize external sources of knowledge for commercial purposes in their respective organizations (Cohen & Levinthal, 1990). This ability generally increases along with improvements in the prior level of knowledge and innovative capabilities. The literature often focuses on the absorptive capacity of individual subsidiaries with host country-specific determinants, which are typically treated as a moderating factor or a control variable for knowledge transfers between MNEs and their subsidiaries (Amendolagine et al., 2018; Minbaeva et al., 2003).

In the present paper, we focus on the influence of absorptive capacity at an aggregate country level on the degree of knowledge transfer and innovative capability in MNE subsidiaries. Specifically, our focus is on the level of different countries' innovative capabilities, drawing on insights from the longstanding literature on the development of these capabilities in developed and developing countries (Lall, 1993; Bell & Pavitt, 1993). Over time, various assessment frameworks and related indicators have been developed to analyze the ability of countries to assimilate, use and develop innovations. An example is the ArCo index proposed by Archibugi and Coco (2004), which considers three main components: the creation of technology, the technological infrastructure and the development of human skills. We recognize that there may be significant differences in innovative capabilities both within and across the different sectors of a given economy (Figueiredo et al., 2020). However, at an aggregate level, we expect countries' absorptive capacity to influence positively the degree to which local affiliates can take advantage of the external knowledge diffused through FDI (De Marchi et al., 2022).

An additional host country-level factor that affects the innovation gains of being a MNE subsidiary is dependence on oil. In Brazil, Goldemberg et al. (2014) found that rents from fossil fuels introduce multiplier effects into the country's economy that may be directed to supporting investments in renewable technologies. Verdolini et al. (2018) studied the deployment of fossil power-based technologies in RE investments across 26 OECD countries, finding that those countries with more knowledge of fossil-fuel technologies are more likely to invest in RE generation, which suggests a technological complementarity. Conversely, in a study on the Middle East and North African (MENA) region, Awijen et al. (2022) found that the availability of natural resources (such as oil and coal) does not favor the deployment of renewable energy. Thus, as the evidence is mixed, against this backdrop we investigate whether being a subsidiary in a country with a high reliance on fossil-fuel exports leads to a higher or a lower quantity and quality of innovation in RE technologies with respect to domestic companies.

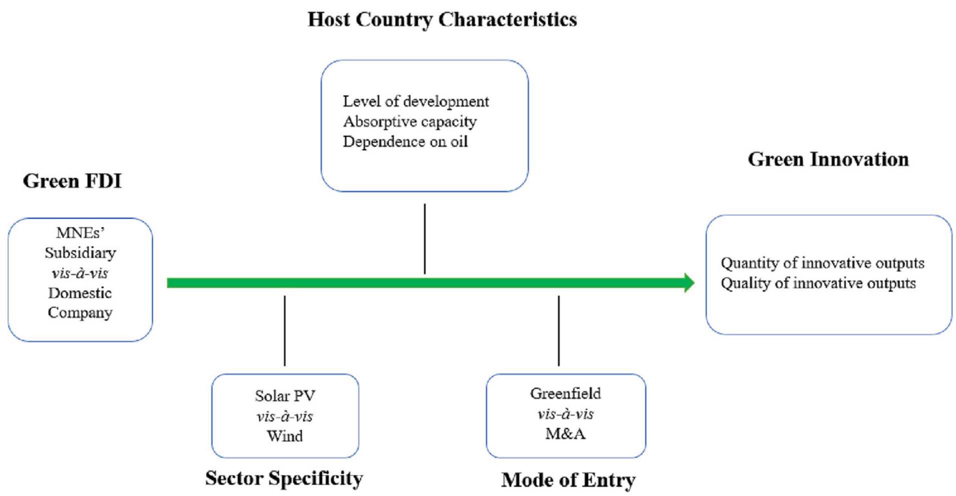

Fig. 1. The empirical framework.

Overall in the empirical analysis, we explore differences in the technological gap between MNE subsidiaries and domestic companies located in high-income and middle-income countries (Noailly & Ryfisch, 2015), between more innovative versus less innovative countries (Amendolagine et al., 2021b) and between countries with different degrees of economic reliance on fossil-fuel sources of energy (Awijen et al., 2022; Chen et al., 2021; Jiang et al., 2021).

2.2. Sector-specificity

From the literature on sectoral systems of production and innovation, it is well-known that specific sectors can differ fundamentally in several respects, such as in their specific knowledge bases, the main actors and technologies, innovation dynamics, inputs and demand structures (Malerba, 2002). A seminal paper by Pavitt (1984) introduced a typology distinguishing between supplier-dominated, science-based, scale-intensive and production-intensive sectors, which was subsequently elaborated further by Castellacci (2008) and others. Jensen et al. (2007) suggested that industries differ in their dominant modes of innovation, and they distinguished between sectors dominated by science, technology and innovation (STI) and those based on doing, using and interacting (DUI). The STI mode is characterized by innovation involving science-based knowledge, such as basic and applied research, including formalized R&D and 'learning-by-searching' in laboratories by trained scientists, and the systematic development of products and processes, often through university–industry cooperation (Parrilli & Heras, 2016). Both the inputs and the outputs of such innovative activity tend to be in the form of codified information, such as scientific documents and reports, patents, technical specifications, electronic files, blueprints and the like (Asheim & Coenen, 2006). In contrast, the DUI mode of innovation involves experience-based knowledge and on-the-job problem-solving based on the exchange and accumulation of practice through learning-by-doing. The knowledge base for DUI innovation tends to involve person-embodied and tacit know-how associated with the context in question (Figueiredo et al., 2020).

With a focus on RE technologies, Huenteler et al. (2016) and Binz et al. (2017) have conceptualized the wind-turbine industry as being mostly characterized by the DUI mode of innovation, while the solar PV industry is typically based on the STI mode of innovation. Wind turbines often involve a degree of customization of projects to context-specific circumstances and inter-project-based learning in which knowledge is often person-embodied and accumulates gradually over time (Prencipe & Tell, 2001). In contrast, like mass-produced commodities, solar PV technology can be standardized to a greater degree in terms of both the production process and the design and implementation of projects. In this vein, Binz and Truffer (2017) argue that the wind-turbine industry is spatially 'sticky' and that accumulated knowledge is mainly tacit, being confined within the local and institutional system in question. Conversely, the solar PV industry is spatially footloose because of the dominance of codified knowledge, which is transferred more easily and at less cost across space (Binz et al., 2020). For example, design specifications, written instructions, manuals, codes, databases and blueprints can be distributed swiftly worldwide using various digital means of communication (Rabbiosi, 2011). This may resonate with a stream of studies about knowledge transfer in the MNE–subsidiary relationship that have argued that the transfer of tacit knowledge may be costly and time-consuming due to the need for frequent face-to-face interaction (Pedersen et al., 2002). The literature discussed so far may suggest that, inter alia, knowledge transfer in the solar PV industry is much easier with respect to the wind-turbine industry because of a greater presence of codified knowledge, typical of an STI mode of innovation.

Nevertheless, Quitzow et al. (2017) reach a different conclusion in their analysis of knowledge transfer in the Chinese solar and wind industries. They conclude that, in the latter, intra-firm mechanisms have remained the dominant mode of knowledge transfer, initially mainly in the form of joint ventures, and later increasingly with the M&As of mainly European technology suppliers and design firms undertaken by Chinese companies. Instead in the solar industry, FDIs have played a minor role in technology transfers, which have been dominated by trade in production equipment, foreign-trained Chinese returnees, and at a later stage joint research with foreign institutions.

Based on the above, we can conclude that sectoral specificity and the nature of the technology and innovation mode in the different RE industries do play a role in effecting knowledge transfers from MNEs to their subsidiaries and, consequently, in whether and how FDI enhance green innovation capacity at the subsidiary level. Nevertheless, the existing empirical evidence does not agree about how the differences identified between solar and wind could impact on the subsidiary's green innovation capacity. Using a novel form of empirical analysis, we aim at offering additional, original evidence in a still-undefined field.

2.3. Mode of entry

The literature includes discussions about the different effects of greenfield investments and acquisitions on the degree of knowledge transfer in MNE–subsidiary relationships. A prevailing argument is that acquisitions involve a greater degree of knowledge transfer from parent MNEs due to the subsidiaries' ability to exploit and integrate already accumulated knowledge with the capabilities provided by the corporate parent (Dezi et al., 2018; Ferraris et al., 2017). Moreover, with respect to greenfield subsidiaries that rely mostly on foreign investors' knowledge, acquired companies have easier access to local knowledge and suffer less from the liability of foreignness (Blomkvist et al., 2014).

This has also been confirmed in the context of green innovation by Li (2022), who investigated the role of technology-driven M&As in acquiring advanced technologies and human capital for 229 Chinese companies, arguing that acquisitions are the quickest way to obtain technical resources, improve the target's absorptive capacity and sustain green innovation. The motivation is that firms involved in cross-border M&As have a strong learning incentive, promoting a deep understanding of green technologies and enhancing innovation capability.

Nonetheless, the literature also contains contributions pointing to the difficulties that acquired subsidiaries might face in remaining outsiders in the corporate network, due, for example, to persistent distant cognitive structures and cultures (Mudambi et al., 2014). Many examples exist in the literature of international acquisitions failing to achieve organizational and cultural integration with their parent company (e.g., Birkinshaw et al., 2010). Conversely, subsidiaries established with greenfield investments may be regarded as insiders in the corporate network, mirroring their parent companies' structures, which facilitates knowledge transfer and their reliance on the parent company's knowledge (Konara et al., 2021). Moreover, in newly established entities, the parent MNE may also devote specific knowledge-transfer activities aimed at developing the subsidiary's innovative capabilities (Mudambi et al., 2014).

Based on these insights, there are convincing arguments in favor of both greenfield investments and acquisitions resulting in higher degrees of knowledge transfer and innovative capability building in local affiliates. Our empirical analysis aims at providing further evidence with a focus on RE.

3. Data and methodology

Green FDIs are defined as foreign direct investments undertaken by firms with at least one climate change-related technology patent in the following RE technologies: geothermal; hydro; marine; solar (including thermal, solar photovoltaic; solar thermal-PV hybrid); wind; biofuels; and fuel from waste.[3] The database includes 1,217 green FDIs in the period from 2003 to 2015 (Amendolagine et al., 2021a), from which we omit investments with missing information at the subsidiary level. The remaining FDIs are 1,055: 73 per cent greenfield investments and 27 per cent mergers and acquisitions (M&A).

In the database, we have information about: (a) the location of the subsidiaries in high-income vs. middle-income countries; b) in more and less innovative countries; c) in countries relying on fossil energy; (d) the investors' green innovative capabilities and in some specific green technologies, such as wind and solar[4]; and (e) the entry mode of the FDI, distinguishing between greenfield investments and acquisitions.

Table 1 presents the distribution of the investments included in the database and shows that 74% of FDIs are hosted in high-income countries, with the UK receiving 14% of the total, followed by Germany (8.7%) and the US (6.4%). Middle-income countries receive 26% of the investments included in our sample. Among them there are large recipients such as China (8.1%), and India (6.9%).[5]

To account for innovative activity in RE technologies, all the patents granted to both investors and their subsidiaries are considered, and then patents are attributed to subsidiaries if at least one of the inventors is resident in the same country as the subsidiary (Stiebale, 2016). Patent data are withdrawn from the PATSTAT database.[6] Here we consider DOCDB families for two reasons (Amendolagine et al., 2021a). First, families avoid potential double counts, since they include patent applications covering a single invention. Second, given the multi-country dimension of the dataset, families account for a multiplicity of patent offices.

In the empirical analysis, we compare the green innovative performance of FDI subsidiaries with a counterfactual sample of green companies which have all their activities within the domestic boundaries. To identify the counter group, given that green FDI subsidiaries are affiliates of investors with at least one patent in RE technologies, we considered domestic companies with at least one patent in RE technologies. Following Amendolagine et al. (2021b), we select domestic companies operating in the same industry (defined at NACE 2-digit level) and located in the same country as the subsidiaries. The counter-sample includes 6,276 companies. Since our sample includes FDIs undertaken in different years, to assign counterfactual treatment dates to the firms included in the control group, we follow the procedure described in Chari et al. (2012) of adopting a proportional random investment time assignment approach to ensure that the counterfactual sample has the same time distribution as the investments in the treated group.

The output variables are the following:

- *Green Patents* calculated as the number of RE patents applied by the investors in a given year (Amendolagine et al., 2018; Stiebale, 2016);
- *Forward Citations* measuring the quality of patents are the average numbers of forward citations to the green patents applied by the investors each year (Perri & Andersson, 2014; Phene & Almeida, 2008).

Given the count nature of the dependent variables, we estimate the impact of green FDI on the innovation performance of subsidiaries from the year of the investment up to five years after the deal using a Negative Binomial regression model (Piperopoulos et al., 2018).

As indicated in Fig. 1, the effect of green FDI on the subsidiaries' innovative capabilities is mediated by different sets of determinants.[7] The first set of variables at the country level includes (a) country GDP per capita (in log) (*COUNTRY GDP PC*); (b) the number of patents per capita (in log) (*COUNTRY PATENT PC*); and (c) the share of oil rents in GDP (*OIL RENTS*).

[3] The CPC (Cooperative Patent Classification) codes are geothermal (Y02E10/1), hydro (Y02E10/2), marine (Y02E10/3), solar thermal (Y02E10/4), solar photovoltaic (Y02E10/5), solar thermal-PV hybrid (Y02E10/6), wind (Y02E10/7), biofuels (Y02E50/1) and fuel from waste (Y02E50/3).

[4] We consider the RE technology in which the investors have more patents.

[5] The income classification of host countries is based on World Bank country groups.

[6] Following Yu et al. (2021) we have checked patents extracted from PATSTAT to identify the presence of design patents and utility models. None of the green patents included in the sample is a utility model or a design patent.

[7] To limit endogeneity issues related to potential omitted variables, we include control variables at both the host country and company levels (see Wooldridge, 2002). Summary statistics of those variables for, respectively, FDI subsidiaries and domestic firms are provided in Tables A2 and A3 in the Appendix.

Table 1
Investments by countries and regions.

Country	Investments (#)	Share(%)
High-income countries*	861	74.42
United Kingdom	167	14.43
Germany	101	8.73
United States	74	6.40
Italy	44	3.80
Netherlands	44	3.80
Spain	41	3.54
France	39	3.37
Australia	38	3.28
Greece	24	2.07
Poland	22	1.90
Middle-income countries*	296	25.58
Upper middle-income countries	203	17.54
China	94	8.12
Brazil	36	3.11
Mexico	14	1.21
Thailand	12	1.04
Malaysia	10	0.86
Turkey	9	0.78
Lower middle-income countries	93	8.04
India	80	6.91
Ukraine	4	0.35
Philippines	3	0.26
Indonesia	3	0.26
Total	1,157	100

*Based on World Bank country classification by income level 2022–23.

The second set of control variables at the company level includes: (a) the pre-deal knowledge base, measured by the number of all patents up to one year before the investment (*PATENT PORTFOLIO STOCK LAG* 1); (b) age (in log), measured as the difference between the investment year and the year the company was established (*AGE*); (c) the company's size, measured by two dummy variables (*MIDDLE SIZE* and *LARGE SIZE*)[8]; and (d) a dummy variable taking a value of 1 if the subsidiary is in the manufacturing industry, based on the NACE two-digit classification[9] (*MANUFACTURING*). Firm-level information is withdrawn from two databases: Bureau van Dick Orbis and PATSTAT. All models include fixed effects for companies' industry, defined at NACE two-digit level,[10] and deal year. The list of all variables is presented in Table A1 in the Appendix.

Third, to account for the impact of the different industry specializations and modes of entry, we test the following sub-samples: (a) FDIs in wind technology vis-à-vis FDIs in solar technology, and (b) greenfield investments vis-à-vis cross-border acquisitions. For each of the sub-samples we build a proper counter-sample, selecting domestic companies in the same industries/countries as the subsidiaries included in the main sample, and running the proportional random investment time assignment method used by Chari et al. (2012).

Tables A2 and A3 in the Appendix show the descriptive statistics for the sample of subsidiaries and for the companies included in the counterfactual sample.

[8] We use dummy variables to measure company size because continuous dimensions are missing for about 70% of the companies in the dataset. In a robustness check, reported in Table A5 in the Appendix, we replace dummies with the value of company sales (in thousand US) in the last available year, sourced from the Orbis database. There are not significant changes in the results.

[9] NACE two-digit codes for manufacturing range from 10 to 33.

[10] In the econometric tests on sub-samples, due to the lower number of observations, and to avoid convergence problems related to count regression models, we substitute NACE two-digit fixed effects with a dummy distinguishing between manufacturing and non-manufacturing sectors.

4. Empirical findings

In the econometric analysis, we address a general question about the role played by green FDIs in sustaining the innovative capabilities of subsidiaries and present the findings in Section 4.1. Then we investigate how different host-country characteristics can influence the results (Section 4.2) and whether and how the role of green FDIs on subsidiaries' innovative capacity is influenced by technological specificity. To do so we test investments in solar PV compared to wind industries (Section 4.3), and using different mode of entry, analyze greenfield investments compared to cross-border acquisitions (Section 4.4). Section 4.5 presents some robustness checks that confirm our main findings.

4.1. Subsidiaries of green FDI vis-à-vis domestic green companies

When testing the full sample, including all green FDI (Table 2), we find that subsidiaries of MNEs outperform comparable domestic companies included in the control sample with respect to both output variables: (a) the number of green patents, and (b) the average number of forward citations. Regarding the number of patents, there is a positive impact in the fourth and fifth years after the investment, while observing the number of forward citations, which measures the qualitative impact on the subsidiaries' innovative capacity, there is a significant positive and increasing difference in all five years after the investment. This is an interesting detail showing that the superior performance in terms of the quality of the green innovativeness of subsidiaries when compared to domestic producers is increasing over time, confirming the general advantage in innovation of MNE subsidiaries with respect to domestic companies (see Un, 2011, 2016; De Marchi et al., 2022). Moreover, the estimation shows that the impact in terms of patent quality, as measured by forward citations, is immediate because subsidiaries' patents benefit from the reputation of the headquarters (Awate et al., 2012), while to increase the number of patents requires more time (Hansen et al, 2020).

Several previous studies have also confirmed the role of multinational companies as a knowledge channel for green innovation. For example, in Spain Melane-Lavado et al. (2018) find that FDIs generate positive spillovers and that SMEs under foreign ownership are more suited to developing innovations oriented to sustainability compared to SMEs without foreign ownership. Similarly, Chiarvesio et al. (2015) studies a sample of Italian firms specializing in medium- and low-tech industries and found that belonging to a multinational group positively spurs the development of environmental innovations. In their analysis of fourteen European countries, De Marchi et al. (2022) argue that subsidiaries in the manufacturing sector take advantage of the intra-MNE knowledge flows, as well as of the flows outside the multinational in the domestic context (e.g., cooperating with other subsidiaries), providing key inputs to green innovation in the host economy.

Our study adds to the existing country-level evidence and shows that these conclusions hold on a global-scale level and across countries at different levels of development. Our empirical analysis reveals that foreign ownership increases the propensity to engage in environmental innovation not only in the manufacturing and service sectors in general (that is, energy users), but specifically in green technology sectors that are at the heart of the transformation towards sustainability (that is, renewable energy producers).

To substantiate and understand these findings better, we also examine several control variables. At the firm level, the pre-deal knowledge base is negatively and significantly related to the post-deal green innovative performance of subsidiaries. In other words, the accumulation of patents (in general) constrains the pro-

Table 2
Full sample.

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−0.859*** (0.262)	−0.049 (0.262)	0.188 (0.249)	0.377 (0.263)	0.705*** (0.245)	0.552** (0.274)	1.167*** (0.375)	1.154*** (0.352)	1.202*** (0.399)	1.510*** (0.361)	2.115*** (0.357)	2.187*** (0.376)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.690** (0.306)	−0.614*** (0.171)	−0.626*** (0.211)	−0.145 (0.144)	−0.518** (0.208)	−0.172 (0.166)	−1.029*** (0.187)	−1.056*** (0.167)	−1.099*** (0.260)	−1.049*** (0.365)	−1.026*** (0.234)	−0.666*** (0.257)
AGE (LN)	−0.314*** (0.071)	−0.249*** (0.071)	−0.189*** (0.072)	−0.244*** (0.074)	−0.087 (0.072)	−0.156* (0.086)	−0.072 (0.085)	−0.414*** (0.077)	−0.281*** (0.087)	−0.226** (0.090)	−0.125 (0.092)	−0.003 (0.097)
MIDDLE SIZE	0.093 (0.165)	0.173 (0.182)	0.066 (0.169)	0.138 (0.181)	0.105 (0.208)	0.934*** (0.221)	−0.127 (0.204)	−0.150 (0.214)	0.021 (0.230)	−0.040 (0.249)	0.015 (0.244)	0.815*** (0.264)
LARGE_SIZE	0.350* (0.188)	0.088 (0.200)	0.308 (0.199)	0.398** (0.193)	0.405** (0.206)	1.064*** (0.241)	−0.313 (0.232)	0.067 (0.241)	−0.487** (0.230)	−0.154 (0.280)	0.507** (0.250)	0.741** (0.345)
COUNTRY GDP PC (LN)	0.106 (0.068)	0.010 (0.063)	0.029 (0.069)	0.150* (0.077)	−0.004 (0.072)	−0.081 (0.074)	0.250*** (0.083)	0.305*** (0.083)	0.255*** (0.089)	0.458*** (0.104)	0.360*** (0.083)	0.228** (0.092)
COUNTRY PATENT PC (LN)	0.131 (0.148)	0.466*** (0.154)	0.265 (0.166)	0.422** (0.170)	0.764*** (0.195)	1.062*** (0.206)	0.384* (0.202)	−0.032 (0.218)	0.242 (0.248)	−0.165 (0.196)	0.353 (0.242)	0.921*** (0.260)
OIL RENTS (% GDP)	−0.049 (0.043)	−0.061 (0.038)	−0.082* (0.042)	−0.063 (0.053)	−0.023 (0.038)	0.011 (0.055)	−0.145*** (0.046)	−0.074* (0.043)	−0.156*** (0.050)	−0.012 (0.068)	−0.064 (0.043)	0.192 (0.133)
INDUSTRY FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−19.082	−20.876*** (1.222)	−21.553 .	−22.229 .	−20.192*** (0.858)	−20.596*** (1.914)	−21.540*** (1.409)	−27.152 (9090.162)	−36.194 (8447873.262)	−31.572 .	−23.094*** (0.613)	−27.666 (125.124)
LNALPHA	2.462*** (0.164)	2.838*** (0.101)	2.788*** (0.107)	2.870*** (0.113)	2.983*** (0.112)	3.171*** (0.110)	4.048*** (0.071)	4.087*** (0.072)	4.148*** (0.081)	3.996*** (0.082)	4.044*** (0.084)	4.177*** (0.097)
OBSERVATIONS	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331

FDI subsidiaries = 1,055. # Domestic companies = 6,276. Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$″.

Table 3
Interaction terms (full sample).

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−2.042**	−1.498*	−1.182	0.017	0.143	0.242	1.730**	2.486***	2.081**	3.302***	3.251***	2.770***
	(0.864)	(0.845)	(1.202)	(0.734)	(0.574)	(0.593)	(0.789)	(0.818)	(0.922)	(0.791)	(0.686)	(0.650)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.728**	−0.746***	−0.699***	−0.169	−0.575***	−0.255	−0.978***	−1.018***	−1.030***	−0.986***	−1.343***	−0.826***
	(0.293)	(0.194)	(0.242)	(0.150)	(0.215)	(0.178)	(0.181)	(0.171)	(0.265)	(0.311)	(0.247)	(0.237)
AGE (LN)	−0.323***	−0.254***	−0.187**	−0.239***	−0.087	−0.175**	−0.077	−0.419***	−0.297***	−0.252***	−0.211**	−0.042
	(0.070)	(0.075)	(0.077)	(0.073)	(0.071)	(0.085)	(0.084)	(0.077)	(0.087)	(0.090)	(0.093)	(0.097)
MIDDLE SIZE	0.094	0.153	0.036	0.123	0.073	0.945***	−0.104	−0.122	0.037	−0.087	0.145	0.848***
	(0.163)	(0.180)	(0.165)	(0.181)	(0.204)	(0.219)	(0.205)	(0.210)	(0.232)	(0.246)	(0.240)	(0.269)
LARGE SIZE	0.368**	0.121	0.331*	0.403**	0.435**	1.162***	−0.298	0.139	−0.461**	−0.136	0.634**	0.895***
	(0.186)	(0.202)	(0.200)	(0.193)	(0.208)	(0.240)	(0.235)	(0.246)	(0.230)	(0.278)	(0.255)	(0.339)
COUNTRY GDP PC (LN)	0.062	−0.035	−0.030	0.115	−0.028	−0.070	0.331***	0.403***	0.324***	0.496***	0.577***	0.440***
	(0.068)	(0.061)	(0.064)	(0.075)	(0.078)	(0.083)	(0.087)	(0.088)	(0.098)	(0.119)	(0.093)	(0.117)
COUNTRY PATENT PC (LN)	0.101	0.360**	0.192	0.395**	0.648***	0.892***	0.301	−0.157	0.166	−0.084	0.070	0.491*
	(0.148)	(0.156)	(0.168)	(0.174)	(0.200)	(0.211)	(0.199)	(0.219)	(0.250)	(0.202)	(0.246)	(0.262)
OIL RENTS (%GDP)	−0.037	−0.050	−0.079*	−0.054	−0.038	0.003	−0.153***	−0.049	−0.143***	0.006	−0.079	0.139
	(0.043)	(0.039)	(0.045)	(0.055)	(0.042)	(0.056)	(0.049)	(0.044)	(0.053)	(0.070)	(0.048)	(0.171)
FDI SUBSIDIARY * COUNTRY GDP PC	**0.334**	**0.254**	**0.277**	**0.083**	**−0.079**	**−0.263**	**−0.390***	**−0.660*****	**−0.445***	**−0.233**	**−1.292*****	**−0.966*****
	(0.288)	**(0.240)**	**(0.344)**	**(0.221)**	**(0.180)**	**(0.179)**	**(0.224)**	**(0.219)**	**(0.249)**	**(0.241)**	**(0.220)**	**(0.189)**
FDI SUBSIDIARY * COUNTRY PATENT PC	**0.471**	**2.111****	**1.530***	**0.548**	**2.030****	**2.918*****	**1.286**	**2.467****	**1.403**	**−1.777**	**6.497*****	**5.463*****
	(0.925)	**(0.900)**	**(0.896)**	**(0.770)**	**(0.844)**	**(0.869)**	**(1.156)**	**(1.123)**	**(1.261)**	**(1.091)**	**(1.076)**	**(1.137)**
FDI SUBSIDIARY * COUNTRY OIL RENTS	**−0.070**	**−0.086**	**−0.024**	**−0.109**	**0.074**	**−0.071**	**−0.070**	**−0.604*****	**−0.253**	**−0.858*****	**−0.064**	**−0.193**
	(0.115)	**(0.127)**	**(0.138)**	**(0.120)**	**(0.099)**	**(0.147)**	**(0.206)**	**(0.204)**	**(0.190)**	**(0.247)**	**(0.168)**	**(0.237)**
INDUSTRY FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−20.379	−21.262***	−19.904***	−21.323**	−20.276***	−20.766	−22.385***	−24.177	−35.701	−19.287***	−24.453***	−32.564
	.	(2.125)	(1.223)	(9.381)	(0.975)	.	(3.576)	.	.	(0.834)	(0.987)	(7659.261)
LNALPHA	2.456***	2.816***	2.766***	2.865***	2.977***	3.160***	4.043***	4.072***	4.139***	3.985***	3.991***	4.120***
	(0.160)	(0.097)	(0.111)	(0.115)	(0.112)	(0.110)	(0.071)	(0.072)	(0.080)	(0.082)	(0.082)	(0.098)
OBSERVATIONS	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331

FDI subsidiaries = 1,055. # Domestic companies = 6,276. Robust standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01″.

duction of green patents by MNE subsidiaries. This confirms Barbieri et al. (2020) and Orsatti et al. (2020) who show that green patents require a large recombination of ex-ante technological capabilities and that the larger the accumulated patenting experience, the lower the probability of creatively recombining ex-ante knowledge. In addition, Orsatti et al. (2020) argue that more experienced teams of inventors are more likely to maintain their focus on more established and traditional technologies.

Size and age are positively related with both outputs. The finding about size is well established in the literature, being confirmed among many others by Shefer and Frenkel (2005), who find that large companies are more intensively involved in R&D activities (see also Govindarajan et al., 2019; Del Brío & Junquera, 2003). The finding about age is consistent with a study by Leyva-De la Hiz & Bolívar-Ramos (2022), who found that younger firms are more likely to capitalize on environmental innovations to improve their performance because they are more risk-prone and less hesitant to develop green strategies and pursue environmental opportunities.

Accounting for host countries' characteristics, we observe a positive and significant impact on the quality of green innovation for subsidiaries located in higher income countries, as well as in those that are less reliant on oil rents. Moreover, in the last year of investigation, the relationship also becomes positive and significant for subsidiaries located in more innovative countries. When considering the number of green patents, there is a positive and significant relationship with innovative capacity at the country level, measured by the aggregate number of patents.

Given the findings reported above, the overall conclusion is that globalization spurred by MNEs is an effective vehicle for the international diffusion of green technological knowledge. In the next section, we explore this general conclusion in conjunction with moderating factors at the host-country level.

4.2. Host-country moderating effects

Table 3 introduces the interaction terms between the dummy variable identifying green FDI subsidiaries and three host-country characteristics: the level of development, the number of patents, and the dependence on oil rents. The first interaction term exploring the influence of the host country's level of development, measured by the GDP per capita, has a negative and significant coefficient for the dependent variable measuring the average number of forward citations to the green patents. This finding means that, all else being equal, in countries with lower GDP per capita, the subsidiaries of multinationals are more innovative than domestic companies in terms of the quality of their patents. The explanation is based on the greater technological advantages of MNE subsidiaries over domestic counterparts in middle-income countries, where the latter companies might suffer to a greater extent from the liability of being local (Un, 2011, 2016). As Mathews and Cho (1999) argue, developing-country firms very often suffer from dislocation from the core centers of innovation and from limited access to skilled labor, advanced technologies and more sophisticated markets. In such contexts, MNE subsidiaries may significantly benefit from their links to their parent companies. In many cases, MNEs may deliberately transfer knowledge to their subsidiaries to support the strengthening of their innovative capabilities (Cantwell & Mudambi, 2005). The case study presented in Hansen et al., 2020, and discussed above, is an excellent example of how, over a long period of time, a parent company made significant investments to improve the innovative capacities of its Indian affiliate. Eventually, the direction of knowledge transfer was reversed from the subsidiary to the Danish parent company, alongside the gradual improvement of the subsidiary's innovative capabilities (see also Mudambi et al., 2014). In contrast, MNE subsidiaries located in higher income countries have easier, more independent access to advanced technology and skilled labor and can innovate without relying on their links to their parent companies to the same degree.

Exploring the role played by the host country's innovative capacity as an interaction term, we find that the advantage of being a subsidiary is greater in more innovative countries (measured by patents per capita). This result holds for both the output variables – the number and quality of green patents as measured by forward citations – and it is consistent with work by De Marchi et al. (2022). Greater innovativeness in the host country is a signal of a greater capacity to absorb cross-border technological transfers via FDI, which is an advantage in terms of transferring innovativeness to MNE subsidiaries (Walz & Ostertag, 2009). To boost their innovative capacities, subsidiaries can positively combine a high degree of general innovative capacity available in the host country with the specific foreign knowledge acquired through their interactions with their investors. Dense and knowledge-intensive links within MNEs' networks are more effective if the local knowledge base is well-developed. Even though domestic companies have access to local knowledge, all being equal, they do not have privileged access to the global knowledge that is available through intense linkages with MNEs, as is the case for the subsidiaries. Hence, MNE affiliates have an advantage in terms of innovative capacity over domestic firms in highly innovative countries.

To explore further the previous results pointing at two different and very relevant host-country characteristics – the level of development and the degree of existing absorptive capacity – we test a new model presented in Table 4 in which we isolate the role of China and India as outliers among middle-income countries, receiving respectively 94 (32%) and 80 (27%) of a total of 296 investments going to middle-income countries and being characterized by a relatively high degree of innovative capacity with respect to other countries at a similar level of economic development.[11] In the new model we introduce two dummies: one for China and India, the other for all the other middle-income countries (i.e. excluding China and India).[12] We find that, while green FDI subsidiaries located in China and India outperform domestic counterparts in green innovation more than other subsidiaries located in high-income economies, the coefficient is negative for the remaining middle-income countries, meaning that the combination of middle incomes and good innovative capacity exemplified by China and India is what really enhances the positive contribution of MNEs on green innovation in their subsidiaries with respect to domestic companies.

Going back to Table 3, the third interaction effect examines dependence on oil. A high degree of reliance on oil rents in the host countries reduces the advantage of being an MNE subsidiary in terms of the quality of the patents in green technologies. MNEs do not foster the development of green innovative capabilities in their subsidiaries when they are in oil-dependent countries. Although there is scant research addressing MNEs' innovative activity in countries that are reliant on fossil-fuel revenues, Awijen et al. (2022) find that in the MENA region countries that are more reliant on oil exports are less likely to foster renewable energy deployment. This result highlights the resource curse hypothesis with respect to renewables. This is also confirmed by Poudineh et al. (2018), who emphasize how MENA countries heavily subsidize fossil fuels to support low-income consumers and energy-intensive industries. Therefore, removing such subsidies

[11] According to the Global Innovation Index 2022 published by the World Intellectual Property Organization (WIPO), China ranks 11th and India 40th out of 132 countries. China is also a global leader in the group of upper middle-income countries, while India comes at the top among lower middle-income countries.

[12] Table A1 provides details of the two dummies.

Table 4
Interaction terms (full sample) with dummy for China and India.

	OUTPUT: # green patents						**OUTPUT: # forward citations to green patents**					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−0.854* (0.469)	−0.627 (0.457)	−0.083 (0.438)	0.307 (0.474)	−0.044 (0.415)	−0.555 (0.422)	0.702 (0.548)	0.636 (0.553)	1.348** (0.654)	2.804*** (0.638)	−0.685 (0.543)	−0.208 (0.661)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.737** (0.304)	−0.760*** (0.192)	−0.732*** (0.240)	−0.213 (0.147)	−0.701*** (0.220)	−0.342** (0.172)	−1.175*** (0.183)	−1.143*** (0.177)	−1.194*** (0.278)	−1.138*** (0.335)	−1.770*** (0.262)	−0.870*** (0.206)
AGE (LN)	−0.314*** (0.071)	−0.252*** (0.072)	−0.191*** (0.073)	−0.250*** (0.072)	−0.086 (0.069)	−0.187** (0.083)	−0.119 (0.082)	−0.417*** (0.076)	−0.259*** (0.085)	−0.204** (0.092)	−0.112 (0.089)	−0.005 (0.100)
MIDDLE SIZE	0.108 (0.163)	0.211 (0.178)	0.079 (0.163)	0.181 (0.179)	0.112 (0.197)	0.983*** (0.214)	0.013 (0.204)	−0.155 (0.214)	0.146 (0.239)	0.076 (0.239)	0.018 (0.232)	0.858*** (0.280)
LARGE SIZE	0.361* (0.184)	0.167 (0.198)	0.367* (0.195)	0.438** (0.187)	0.454** (0.205)	1.206*** (0.238)	−0.112 (0.231)	−0.013 (0.239)	−0.497** (0.228)	−0.083 (0.255)	0.496** (0.250)	0.845** (0.350)
CHINA&INDIA	−0.228 (0.294)	−0.175 (0.270)	0.179 (0.302)	−1.531*** (0.405)	0.041 (0.439)	−0.065 (0.420)	−0.011 (0.418)	−0.701* (0.361)	0.042 (0.361)	−2.898*** (0.488)	−1.844*** (0.441)	−0.499 (0.505)
MIDDLE INCOME_NO_CHINA&INDIA	−1.285*** (0.386)	−1.224*** (0.451)	−1.048*** (0.400)	−0.943** (0.384)	−0.593 (0.403)	−0.872** (0.408)	−2.874*** (0.548)	−2.618*** (0.413)	−3.112*** (0.779)	−2.651*** (0.491)	−3.209*** (0.554)	−4.355*** (1.290)
COUNTRY PATENT PC (LN)	0.027 (0.152)	0.263* (0.159)	0.129 (0.170)	0.262 (0.177)	0.610*** (0.197)	0.789*** (0.208)	0.394* (0.201)	−0.011 (0.220)	0.175 (0.249)	−0.286 (0.214)	0.056 (0.249)	0.500* (0.275)
OIL RENTS (%GDP)	0.007 (0.038)	0.006 (0.040)	−0.037 (0.042)	0.014 (0.047)	0.009 (0.048)	0.062 (0.067)	−0.070* (0.042)	0.068 (0.055)	−0.056 (0.048)	0.140* (0.074)	0.114* (0.067)	0.278 (0.249)
FDI SUBSIDIARY * CHINA&INDIA	−0.143 (0.753)	0.104 (0.704)	−0.859 (0.979)	1.051 (0.700)	0.161 (0.757)	1.341** (0.675)	0.752 (0.778)	2.357*** (0.832)	0.521 (0.972)	1.568* (0.821)	4.258*** (0.924)	2.856*** (0.717)
FDI SUBSIDIARY *MIDDLE INCOME_NO_CHINA&INDIA	−15.862*** (0.608)	−15.237*** (0.624)	−17.774** (7.122)	−17.543*** (1.802)	−3.917*** (1.388)	−17.340*** (0.656)	−20.925*** (0.846)	−18.479*** (0.607)	−18.406*** (1.045)	−20.766*** (0.741)	−3.159** (1.400)	−15.771*** (1.642)
FDI SUBSIDIARY * COUNTRY PATENT PC	0.478 (0.880)	2.056** (0.918)	1.178 (0.925)	0.295 (0.754)	1.595* (0.842)	2.369*** (0.833)	0.591 (1.113)	1.821 (1.198)	0.155 (1.287)	−2.323** (1.064)	5.426*** (1.028)	4.638*** (1.098)
FDI SUBSIDIARY * COUNTRY OIL RENTS	−0.042 (0.182)	−0.103 (0.225)	0.203 (0.285)	0.103 (0.172)	0.515* (0.264)	0.010 (0.217)	0.003 (0.230)	−0.644* (0.369)	−0.009 (0.357)	−0.385 (0.261)	0.529* (0.279)	−0.304 (0.346)
INDUSTRY FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−20.342 .	−20.765 .	−21.118*** (2.053)	−18.721 .	−20.899 .	−20.763*** (2.517)	−19.884*** (0.971)	−18.678 .	−22.720 (36.383)	−18.015*** (0.982)	−23.703*** (1.020)	−29.230 (1476.619)
LNALPHA	2.435*** (0.164)	2.793*** (0.099)	2.732*** (0.108)	2.820*** (0.113)	2.953*** (0.112)	3.105*** (0.111)	4.001*** (0.071)	4.032*** (0.074)	4.082*** (0.080)	3.928*** (0.082)	3.951*** (0.082)	4.040*** (0.105)
OBSERVATIONS	7334	7334	7334	7334	7334	7334	7334	7334	7334	7334	7334	7334

FDI subsidiaries = 1,058. # Domestic companies = 6,276. Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5
Green FDI: Wind.

	OUTPUT: # green patents						**OUTPUT: # forward citations to green patents**					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−0.049	1.352***	1.805***	2.016***	2.194***	2.182***	5.195***	5.087***	4.908***	5.386***	3.386***	4.580***
	(0.376)	(0.367)	(0.476)	(0.366)	(0.427)	(0.410)	(1.059)	(0.716)	(0.852)	(0.942)	(0.551)	(0.693)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.784**	−0.673***	−1.153***	−0.579***	−1.052***	−0.736***	−1.846***	−1.878***	−2.190***	−2.666***	−3.270***	−2.435***
	(0.391)	(0.247)	(0.328)	(0.206)	(0.283)	(0.176)	(0.258)	(0.290)	(0.729)	(0.692)	(0.274)	(0.294)
AGE (LN)	−0.408***	−0.338***	−0.354***	−0.181***	−0.180**	−0.220***	−0.320***	−0.434***	−0.382***	0.095	−0.250***	−0.153
	(0.081)	(0.076)	(0.068)	(0.070)	(0.079)	(0.081)	(0.084)	(0.097)	(0.097)	(0.084)	(0.087)	(0.113)
MIDDLE_SIZE	0.203	0.010	0.325	0.212	0.497**	0.269	−0.188	0.313	0.116	0.414*	0.178	−0.142
	(0.177)	(0.181)	(0.212)	(0.192)	(0.200)	(0.209)	(0.212)	(0.216)	(0.234)	(0.251)	(0.271)	(0.261)
LARGE SIZE	0.868***	0.301	0.049	0.248	0.605***	0.364*	−0.322	0.017	−0.008	0.266	0.623**	0.031
	(0.250)	(0.239)	(0.219)	(0.228)	(0.224)	(0.221)	(0.242)	(0.290)	(0.285)	(0.266)	(0.277)	(0.277)
COUNTRY GDP PC (LN)	0.156	−0.021	0.059	0.194	0.336**	0.183	0.716***	0.381***	0.512***	0.699***	0.469***	0.788***
	(0.124)	(0.096)	(0.116)	(0.127)	(0.132)	(0.129)	(0.126)	(0.104)	(0.121)	(0.132)	(0.139)	(0.149)
COUNTRY PATENT PC (LN)	−0.129	0.373**	0.558***	0.642***	0.199	0.884***	0.216	0.902***	0.919***	0.016	−0.322	0.677**
	(0.184)	(0.183)	(0.154)	(0.174)	(0.179)	(0.167)	(0.232)	(0.265)	(0.215)	(0.217)	(0.243)	(0.266)
OIL RENTS (%GDP)	0.065	0.031	0.142***	−0.020	0.038	−0.010	0.055	0.033	0.126**	−0.062	−0.020	−0.006
	(0.045)	(0.039)	(0.044)	(0.051)	(0.053)	(0.052)	(0.045)	(0.058)	(0.060)	(0.069)	(0.062)	(0.078)
MANUFACTURING	−0.248	0.046	0.312	−0.032	−0.196	−0.282	0.055	−0.021	0.306	0.169	0.529**	−0.279
	(0.185)	(0.185)	(0.197)	(0.194)	(0.221)	(0.186)	(0.225)	(0.233)	(0.231)	(0.215)	(0.246)	(0.266)
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−4.307***	−20.896***	−3.205***	−5.402***	−3.821***	−5.442***	−3.232***	−39.675	−2.686***	−7.409***	−2.330***	−5.121***
	(1.128)	(5.395)	(0.830)	(1.314)	(0.723)	(1.298)	(1.034)	(584405.876)	(0.784)	(1.212)	(0.776)	(1.125)
LNALPHA	2.516***	2.732***	2.782***	2.795***	2.872***	2.834***	3.988***	4.058***	4.053***	4.015***	4.160***	4.113***
	(0.181)	(0.144)	(0.147)	(0.126)	(0.131)	(0.116)	(0.080)	(0.079)	(0.085)	(0.088)	(0.087)	(0.093)
OBSERVATIONS	5930	5930	5930	5930	5930	5930	5930	5930	5930	5930	5930	5930

FDI subsidiaries = 361. # Domestic companies = 5.569. Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

would, at least in the short run, increase the risk of social discontent and economic slowdown, making MENA governments quite reluctant to introduce effective policies to enhance the transition to renewable energies.

Overall, our results provide robust empirical evidence that confirms the non-propensity of MNEs to engage in green innovative activity in oil-reliant countries, where their subsidiaries are even less likely to engage in green innovative activities than domestic companies.

4.3. Sectoral technological specificity: solar PV vis-à-vis wind

To test differences in the technological gap between MNE subsidiaries and domestic companies across different sectors, we divided our sample into investments undertaken by investors specializing in wind (Table 5) and in solar technologies (Table 6).[13] FDI subsidiaries of investors specializing in wind outperform domestic companies in terms of both outputs, while those specializing in solar have an advantage in terms of the number of forward citations and the coefficient of the number of green patents, which is positive and significant only in the fifth year after the investment. Considering the magnitude of the coefficients, the subsidiaries of wind multinationals have a larger positive gap with domestic companies than the subsidiaries of solar-specialized investors in terms of the average number of forward citations.

This result confirms Quitzow et al. (2017), who found that tacit knowledge transfer in the wind sector is more likely to occur within firm boundaries (that is, through joint ventures or FDIs), because it enables large amounts of product-specific knowledge to be transferred. Conversely, in the solar industry, technology transfer mainly takes place through the trade in production equipment (i.e., purchases of machines, license acquisitions), with less reliance on knowledge transfer within the MNEs.

Overall, we can now confirm our initial expectation that the effectiveness of FDIs as channels for transfers of green technology depends on the technological specificities, showing that the subsidiaries' advantage in innovativeness with respect to domestic companies is larger in wind than in solar PV. To explain this result, it is worth mentioning that the knowledge base – that is, the nature of knowledge in the sectors – ranges from tacit to codified knowledge and is highly sector-specific, depending on the maturity and tradability of the different technologies (Lema et al., 2021). Solar PV technology is highly mature, with an established dominant design and an innovation process that is mainly based on incremental improvements in efficiency and price reductions due to economies of scale. Moreover, solar PV technology is highly tradable, characterized by relatively low transportation costs, which makes supplier-to-buyer flows straightforward, with little DUI-based interaction. Wind, on the other hand, is developing faster, with more drastic improvements in efficiency (the so-called levelized cost of energy), several competing designs and still evolving technological developments (Dai et al., 2020). Although the innovation process has become more STI-based over the years (Hendry & Harborne 2011), there is still a large component of DUI involved in knowledge production, involving deep collabora-

[13] To check the robustness of our findings, we have tested two additional models in which the host-country characteristics are considered as moderating factors, following the analysis presented in Table 3. The results, consistent with those in Tables 4 and 5, are available on request.

Table 6
Green FDI: Solar.

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−0.592	−0.124	0.446	0.901	0.398	0.950**	4.109***	3.297***	2.898***	2.415***	4.628***	3.767***
	(0.903)	(0.562)	(0.770)	(0.713)	(0.835)	(0.450)	(0.724)	(0.626)	(0.615)	(0.842)	(0.603)	(0.614)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−3.347***	−3.827***	−3.039***	−2.636***	−2.566***	−1.552***	−3.712***	−3.055***	−3.389***	−3.677***	−2.252***	−2.392***
	(0.692)	(0.634)	(0.713)	(0.552)	(0.847)	(0.487)	(0.340)	(0.419)	(0.289)	(0.333)	(0.306)	(0.409)
AGE (LN)	−0.354***	−0.026	−0.011	0.104	−0.082	−0.010	−0.185*	−0.227**	0.067	0.152	−0.018	0.256**
	0.199	−0.334*	0.173	0.065	−0.333	0.599***	−0.242	0.134	−0.087	0.210	−0.415	0.441
MIDDLE SIZE	(0.199)	(0.189)	(0.174)	(0.179)	(0.208)	(0.212)	(0.212)	(0.222)	(0.217)	(0.253)	(0.285)	(0.280)
	0.403*	0.119	0.269	0.073	0.067	0.376*	−0.240	−0.206	0.060	0.013	−0.950***	0.631**
LARGE SIZE	(0.243)	(0.226)	(0.206)	(0.240)	(0.266)	(0.210)	(0.266)	(0.249)	(0.251)	(0.250)	(0.302)	(0.310)
	0.069	−0.121*	−0.078	−0.064	−0.035	−0.053	0.399***	0.378***	0.290***	0.362***	0.308**	0.295***
COUNTRY GDP PC (LN)	(0.069)	(0.073)	(0.069)	(0.077)	(0.079)	(0.084)	(0.099)	(0.098)	(0.110)	(0.109)	(0.122)	(0.110)
	0.521***	0.359**	0.347*	0.588***	0.826***	0.915***	0.595***	0.560***	0.274	−0.182	0.832***	0.286
COUNTRY PATENT PC (LN)	(0.191)	(0.169)	(0.195)	(0.201)	(0.217)	(0.207)	(0.182)	(0.199)	(0.215)	(0.236)	(0.264)	(0.276)
	−0.016	0.017	−0.058	−0.013	0.009	0.027	0.069	0.012	−0.176***	−0.055	−0.026	0.062
OIL RENTS (%GDP)	(0.039)	(0.034)	(0.040)	(0.038)	(0.040)	(0.045)	(0.062)	(0.060)	(0.055)	(0.048)	(0.070)	(0.106)
	−0.235	−0.388**	−0.680***	−0.447**	−0.216	−0.262	−0.075	−0.556***	−1.112***	0.039	0.189	−1.110***
MANUFACTURING	(0.188)	(0.167)	(0.173)	(0.184)	(0.223)	(0.174)	(0.179)	(0.196)	(0.217)	(0.209)	(0.244)	(0.262)
	(0.159)	(0.157)	(0.182)	(0.186)	(0.196)	(0.194)	(0.189)	(0.185)	(0.195)	(0.212)	(0.228)	(0.268)
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−17.978***	−4.242***	−4.440***	−4.357***	−4.765***	−4.819***	−24.494***	−3.229***	−3.608***	−2.835***	−3.519***	−6.219***
	(0.869)	(1.052)	(1.090)	(0.802)	(1.208)	(0.847)	(8.489)	(0.962)	(1.067)	(1.073)	(1.121)	(1.019)
LNALPHA	2.525***	2.285***	2.777***	2.919***	3.056***	2.715***	3.999***	3.868***	4.086***	4.146***	4.322***	4.116***
	(0.193)	(0.157)	(0.176)	(0.169)	(0.181)	(0.162)	(0.079)	(0.087)	(0.090)	(0.104)	(0.097)	(0.100)
OBSERVATIONS	6463	6463	6463	6463	6463	6463	6463	6463	6463	6463	6463	6463

FDI subsidiaries = 492. # Domestic companies = 5.971. Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

tion between lead firms and suppliers of core components. Hence, a subsidiary focused on critical components such as gearboxes or control systems greatly benefits from intense interactions with the headquarters, aimed at developing the product architecture, as well as linkages to other subsidiaries specializing in other components in the MNE network.

Our findings are aligned with research on transfers of green technology within the clean development mechanisms (CDM). Also, with a focus on wind and solar PV, Lema and Lema (2013; 2016) find similar differences with respect to FDI as a mechanism of technology transfers. In wind, they find that FDI is a major channel of technology transfers, whereas in solar PV, investments only account for a small share of the observed technology transfers.

4.4. Mode of entry: greenfield FDI compared to cross-border acquisitions

Tables 7 and 8 report the results of the econometric tests on the different modes of entry: greenfield investments vis-à-vis cross-border acquisitions.[14] The results in Table 7 show that subsidiaries of greenfield FDIs outperform domestic companies in terms of the number of forward citations, but not in terms of the number of patents. Instead, the results in Table 8 reveal that the targets of cross-border acquisitions perform better in terms of both output variables, that is, the amount and quality of their innovations. Moreover, comparing the results from the tests on the sub-samples, we observe that the gap in terms of innovation quality between MNEs' subsidiaries and local companies is larger in the case of cross-border acquisitions.

This finding suggests that targets of cross-border acquisitions are more likely to undertake green innovation than newly established subsidiaries since they can leverage the combination of their pre-deal knowledge base, as well as the technological knowledge transferred by the acquiring MNE (Dezi et al., 2018; Ferraris et al., 2017; Li, 2022). In comparison with subsidiaries established by greenfield investments, relying mostly on foreign investors' knowledge, the acquired companies have easier access to local knowledge, being less affected by the liability of their foreignness (Blomkvist et al., 2014). Therefore, their innovative capacity is based on the knowledge leveraged from their links with headquarters with the knowledge that comes from their being embedded in the local knowledge pool.

4.5. Robustness checks

A robustness check was undertaken to account for the intensity of environment-related policies in the host countries, which might affect the production of green innovation (Porter & Van der Linde, 1995; Kesidou & Wu, 2020). We add the share of environmentally related tax revenues in GDP at the year of the investment as a control to the model.[15] As shown in Table 9, the introduction of this

[14] Due to convergence issues depending on the limited numerosity of acquisitions, the role of host-country characteristics as moderating factors cannot be tested in the two sub-samples.

[15] Other measures, such as the Environmental Performance Index (EPI) developed in collaboration by Yale University, the Yale Centre for Environmental Law and Policy, and the Columbia University Centre for International Earth Science Information Network, as well as the Environmental Policy Stringency Index developed by OECD, are not available for all the countries and years included in our sample. The environmental tax is a key policy measure through which countries address pollution externalities.

Table 7
Greenfield FDIs.

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−1.134***	−0.133	−0.027	0.408	0.443	0.728*	1.119**	0.869**	0.397	1.920***	1.356***	1.895***
	(0.310)	(0.323)	(0.361)	(0.308)	(0.346)	(0.375)	(0.495)	(0.417)	(0.468)	(0.429)	(0.455)	(0.413)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.716	−0.852*	−0.805**	−0.155	−0.583**	−0.383**	−0.862***	−1.023***	−1.085**	−1.520***	−1.378***	−0.968***
	(0.857)	(0.489)	(0.330)	(0.182)	(0.261)	(0.184)	(0.234)	(0.226)	(0.423)	(0.426)	(0.297)	(0.279)
AGE (LN)	−0.367***	−0.283***	−0.251***	−0.306***	−0.188**	−0.253***	−0.228**	−0.499***	−0.455***	−0.210**	−0.248**	−0.102
	(0.092)	(0.081)	(0.077)	(0.072)	(0.094)	(0.097)	(0.094)	(0.082)	(0.096)	(0.091)	(0.125)	(0.107)
MIDDLE SIZE	0.007	0.160	0.032	0.105	0.048	0.871***	−0.282	−0.070	−0.150	0.125	−0.301	0.738***
	(0.180)	(0.238)	(0.179)	(0.189)	(0.232)	(0.236)	(0.226)	(0.213)	(0.247)	(0.247)	(0.278)	(0.273)
LARGE SIZE	0.395	0.058	0.438*	0.291	0.438*	1.083***	−0.382	0.124	−0.441*	−0.225	−0.000	0.802**
	(0.250)	(0.265)	(0.228)	(0.215)	(0.255)	(0.264)	(0.270)	(0.257)	(0.252)	(0.275)	(0.278)	(0.313)
COUNTRY GDP PC (LN)	0.082	−0.002	0.036	0.191***	0.038	0.080	0.224***	0.437***	0.464***	0.554***	0.309***	0.324***
	(0.087)	(0.071)	(0.069)	(0.074)	(0.074)	(0.075)	(0.087)	(0.085)	(0.105)	(0.118)	(0.096)	(0.100)
COUNTRY PATENT PC (LN)	0.093	0.521***	0.349**	0.491***	0.804***	1.126***	0.669***	0.093	0.210	−0.048	0.402	0.450
	(0.163)	(0.181)	(0.171)	(0.177)	(0.235)	(0.247)	(0.229)	(0.240)	(0.246)	(0.212)	(0.282)	(0.288)
OIL RENTS (%GDP)	−0.051	−0.048	−0.078	−0.051	−0.006	0.004	−0.109**	−0.011	−0.143**	−0.013	−0.004	0.172
	(0.048)	(0.040)	(0.049)	(0.057)	(0.040)	(0.056)	(0.050)	(0.058)	(0.062)	(0.070)	(0.051)	(0.122)
MANUFACTURING	0.170	−0.162	0.054	0.371**	−0.226	−0.082	−0.126	−0.133	0.093	0.547**	0.067	−0.507**
	(0.186)	(0.186)	(0.179)	(0.186)	(0.213)	(0.203)	(0.198)	(0.198)	(0.224)	(0.237)	(0.238)	(0.235)
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−3.555***	−4.043***	−4.385***	−4.624***	−4.106***	−4.644***	−3.756***	−1.560	−2.271***	−4.068***	−5.875***	−3.719***
	(0.814)	(0.781)	(0.842)	(0.736)	(0.738)	(0.723)	(1.022)	(1.012)	(0.862)	(0.883)	(1.271)	(0.719)
LNALPHA	2.584***	2.998***	2.970***	3.053***	3.189***	3.372***	4.212***	4.206***	4.286***	4.123***	4.266***	4.368***
	(0.306)	(0.138)	(0.123)	(0.117)	(0.127)	(0.116)	(0.076)	(0.074)	(0.082)	(0.085)	(0.089)	(0.099)
OBSERVATIONS	7118	7118	7118	7118	7118	7118	7118	7118	7118	7118	7118	7118

FDI subsidiaries = 842. # Domestic companies = 6,276. Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8
Cross-border acquisitions.

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	0.671	2.722	2.475**	2.186*	3.644***	3.791***	8.293***	6.553***	6.930***	6.482***	7.887***	6.474***
	(1.138)	(1.748)	(1.042)	(1.328)	(0.932)	(0.989)	(0.836)	(0.796)	(0.775)	(0.847)	(0.826)	(0.936)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−3.544***	−2.354**	−2.775***	−3.318***	−2.937***	−2.830***	−5.580***	−4.544***	−5.406***	−4.850***	−4.673***	−3.792***
	(0.639)	(1.147)	(0.364)	(0.328)	(0.323)	(0.371)	(0.339)	(0.577)	(0.294)	(0.311)	(0.374)	(0.402)
AGE (LN)	−0.273***	−0.267**	−0.124*	0.106	0.034	−0.023	−0.317***	−0.480***	−0.123	−0.007	−0.091	−0.123
	(0.065)	(0.114)	(0.068)	(0.086)	(0.080)	(0.087)	(0.073)	(0.089)	(0.092)	(0.103)	(0.099)	(0.114)
MIDDLE SIZE	−0.035	0.156	0.331*	0.504***	−0.067	−0.129	−0.636***	0.154	0.140	0.150	0.242	−0.209
	(0.169)	(0.235)	(0.180)	(0.189)	(0.233)	(0.251)	(0.194)	(0.232)	(0.230)	(0.276)	(0.275)	(0.298)
LARGE SIZE	0.003	0.316	0.250	0.688***	−0.515**	−0.341	−0.057	−0.094	0.249	0.273	−0.533*	−0.906***
	(0.187)	(0.285)	(0.206)	(0.245)	(0.252)	(0.259)	(0.229)	(0.232)	(0.267)	(0.277)	(0.323)	(0.334)
COUNTRY GDP PC (LN)	−0.139*	−0.042	−0.023	−0.015	−0.041	−0.210***	0.393***	0.111	0.351***	0.116	0.551***	0.407***
	(0.071)	(0.056)	(0.071)	(0.072)	(0.084)	(0.080)	(0.079)	(0.091)	(0.093)	(0.096)	(0.118)	(0.100)
COUNTRY PATENT PC (LN)	0.302*	0.751***	0.441**	0.821***	0.418**	0.556***	−0.022	0.272	−0.013	0.629**	1.202***	0.474*
	(0.156)	(0.222)	(0.173)	(0.198)	(0.177)	(0.210)	(0.177)	(0.185)	(0.211)	(0.261)	(0.288)	(0.255)
OIL RENTS (%GDP)	−0.012	0.037	−0.009	0.085**	0.001	−0.135**	−0.112**	−0.016	−0.019	0.038	−0.032	−0.171***
	(0.038)	(0.031)	(0.059)	(0.038)	(0.045)	(0.066)	(0.051)	(0.037)	(0.052)	(0.049)	(0.059)	(0.049)
MANUFACTURING	−0.022	−0.346*	0.330*	0.252	−0.266	0.082	−0.471**	−0.344	0.168	−0.130	−0.312	−0.156
	(0.181)	(0.186)	(0.189)	(0.232)	(0.229)	(0.244)	(0.205)	(0.248)	(0.228)	(0.254)	(0.264)	(0.344)
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−21.399	−17.781***	−22.798	−4.385***	−19.187***	−2.750**	−28.815	−24.543*	−34.160	−2.256**	− 23.586***	−28.600
	.	(1.816)	.	(1.327)	(1.411)	(1.149)	.	(14.388)	.	(1.106)	(1.199)	.
LNALPHA	1.999***	2.612***	2.466***	2.790***	2.963***	3.082***	3.617***	3.609***	3.790***	4.002***	4.186***	4.149***
	(0.198)	(0.248)	(0.172)	(0.189)	(0.147)	(0.145)	(0.072)	(0.079)	(0.085)	(0.096)	(0.107)	(0.121)
OBSERVATIONS	5886	5886	5886	5886	5886	5886	5886	5886	5886	5886	5886	5886

FDI subsidiaries = 213. # Domestic companies = 5,673. Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 9
Robustness test for host-country environmental policy.

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−0.779***	−0.077	0.151	0.299	0.693***	0.404	0.860**	0.797**	0.319	1.318***	2.121***	1.880***
	(0.256)	(0.262)	(0.249)	(0.270)	(0.252)	(0.272)	(0.361)	(0.343)	(0.400)	(0.366)	(0.372)	(0.377)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.704**	−0.655***	−0.679***	−0.198	−0.607***	−0.273	−1.002***	−1.100***	−1.095***	−1.155***	−1.113***	−0.774***
	(0.301)	(0.174)	(0.219)	(0.143)	(0.221)	(0.170)	(0.181)	(0.172)	(0.259)	(0.367)	(0.244)	(0.269)
AGE (LN)	−0.290***	−0.271***	−0.215***	−0.308***	−0.111	−0.246***	−0.202**	−0.483***	−0.479***	−0.301***	−0.123	−0.049
	(0.066)	(0.071)	(0.072)	(0.078)	(0.075)	(0.086)	(0.085)	(0.079)	(0.096)	(0.091)	(0.097)	(0.100)
MIDDLE SIZE	0.057	0.217	0.132	0.238	0.164	1.074***	−0.005	−0.034	0.093	0.117	0.043	0.924***
	(0.155)	(0.176)	(0.171)	(0.177)	(0.212)	(0.224)	(0.201)	(0.211)	(0.224)	(0.243)	(0.248)	(0.267)
LARGE SIZE	0.313*	0.112	0.363*	0.500***	0.462**	1.157***	−0.245	0.186	−0.134	0.029	0.431*	0.656**
	(0.185)	(0.196)	(0.201)	(0.192)	(0.207)	(0.239)	(0.224)	(0.232)	(0.240)	(0.281)	(0.254)	(0.331)
COUNTRY GDP PC (LN)	0.046	0.040	0.077	0.246***	0.067	0.079	0.570***	0.474***	0.740***	0.718***	0.624***	0.551***
	(0.069)	(0.070)	(0.073)	(0.081)	(0.083)	(0.087)	(0.083)	(0.091)	(0.118)	(0.129)	(0.100)	(0.108)
COUNTRY PATENT PC (LN)	0.225*	0.477***	0.279	0.406**	0.740***	1.100***	0.062	−0.124	−0.131	−0.293	0.138	0.502**
	(0.136)	(0.156)	(0.171)	(0.173)	(0.199)	(0.212)	(0.184)	(0.208)	(0.244)	(0.202)	(0.243)	(0.244)
OIL RENTS (%GDP)	0.031	0.005	−0.029	−0.182**	−0.054	−0.034	−0.008	0.113	0.032	0.071	0.227	0.233
	(0.055)	(0.054)	(0.058)	(0.085)	(0.074)	(0.115)	(0.072)	(0.079)	(0.107)	(0.090)	(0.183)	(0.178)
ENVIRONMENTALLY RELATED TAX REVENUE (%GDP)	0.166*	−0.044	0.009	−0.145	−0.070	−0.194*	−0.520***	−0.111	−0.575***	−0.532***	−0.408***	−0.517***
	(0.089)	(0.100)	(0.087)	(0.098)	(0.100)	(0.108)	(0.100)	(0.106)	(0.124)	(0.120)	(0.124)	(0.157)
INDUSTRY FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−20.259	−21.262***	−21.041***	−21.614	−20.311***	−20.343***	−19.519***	−25.264	−25.329	−25.077	– 22.190***	−24.782
	.	(5.628)	(1.448)	.	(2.758)	(0.780)	(0.951)	.	.	.	(0.806)	.
LNALPHA	2.443***	2.818***	2.755***	2.831***	2.976***	3.140***	3.986***	4.029***	4.030***	3.915***	3.966***	4.114***
	(0.159)	(0.101)	(0.107)	(0.114)	(0.116)	(0.114)	(0.072)	(0.072)	(0.081)	(0.084)	(0.085)	(0.100)
OBSERVATIONS	7131	7131	7131	7131	7131	7131	7131	7131	7131	7131	7131	7131

FDI subsidiaries = 938. # Domestic companies = 6,133. Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

control does not affect the main results regarding the number of green patents and forward citations in green FDI subsidiaries when compared to domestic firms.

Regarding the impact of environmental regulations, we find a negative and significant relationship with the subsidiaries' green innovative capacity, which could be explained by referring to Du et al. (2021), who find that the relationship between environmental regulations and green innovation is non-linear and dependent on the level of development of the country as a moderating factor.[16]

Besides, we have added some additional host country-level variables to the model: a) the exchange rate capturing currency volatility, representing a potential risk for foreign investors (see Boateng et al., 2015; Okafor et al., 2022); b) the share of labor compensation in GDP at current national prices, a proxy for labor costs; c) a human capital index to account for the availability of R&D personnel and the overall quality of the human capital (Dunning & Lundan, 2008); and d) the country's latitude to capture the potential of solar and wind energy production in host economies (Cruz & Rossi-Hansber, 2023).[17] Table A6 in the Appendix presents the estimation of the model, showing that there are no significant changes in the main findings about the existing positive gap in green innovativeness between green FDI subsidiaries and their domestic counterparts.[18]

5. Discussion and conclusions

Technologies to mitigate climate change may diffuse from green lead markets to the rest of the world through several mechanisms, which contributes importantly to the global green transformation. The possible channels of diffusion are manifold, including international trade, licensing and FDI in climate-mitigation technologies. In the present paper we have focused on the latter, examining how effective FDIs are in transferring green innovative capabilities from parent MNE headquarters to their international subsidiaries.

The empirical analysis offers three related novel findings.

- Subsidiaries of green MNEs are more innovative than locally owned firms with similar characteristics. Therefore, foreign ownership positively impacts on the companies' innovative capabilities, measured by the number and quality of green patents.

[16] Du et al. (2021) find that, at a low level of economic development, environmental regulations reduce green technology innovation; then, at increasing levels of economic development, environmental regulations show relatively weak impacts on green technology innovation. Finally, at high levels of economic development, environmental regulations promote green technology innovation significantly.

[17] Table A1 reports the detailed description of the variables.

[18] Further relevant FDI location factors, such as political stability (as a measure of political risk) and inward FDI stock intensity (as a measure of agglomeration), are closely correlated with the other controls already included in the analysis. Therefore, they are not added to the model. In a separate test, we have included these variables instead of the existing controls discussed in the paper, which shows that our findings do not change significantly. The results are available on request.

- This green innovative advantage vis-à-vis domestic companies is larger in less developed countries and in those that are less reliant on oil rents, in particular if they already possess higher levels of relevant domestic innovative activity, as exemplified by the cases of China and India.
- Firm-level and sectoral characteristics also matter. The effectiveness of FDI as a mechanism of green technology transfer depends on technology specificities. Our analysis suggests that green FDI is more effective when technologies are characterized by low tradability and a large component of DUI involved in knowledge production, as in wind compared to solar PV industries. Furthermore, cross-border acquisitions are more efficient at establishing green innovative capabilities than newly established greenfield subsidiaries.

These findings add to the literature in several ways. While the relationship between MNE headquarters and their subsidiaries might initially be skewed heavily in favor of the leading companies, our analysis shows that, over time, bi-directional knowledge flows based on continuous interactions and a learning process may be established. Thus, the paper contributes to expanding existing empirical evidence concerning the role of green FDI as a channel for low-carbon technology and knowledge transfer and its dynamics (see, e.g., Amendolagine et al., 2021; Noailly & Ryfisch, 2015; Konara et al., 2021).

This is important because MNEs' subsidiaries may become central contributors to building sustainability-oriented innovation systems (Lema et al., 2018; Altenburg & Pegels, 2012). Hence, this finding is not only interesting from a scholarly point of view, given that there is a gap in the literature and only limited empirical knowledge available about the patterns of headquarters–subsidiary innovation in green industries. This is also highly relevant from a policy perspective because it implies that international institutional arrangements of investment-related measures need to be aligned with climate-change objectives.

Our findings on the host-country's characteristics are highly relevant because green FDI could play a positive and significant role in transferring innovative knowledge towards subsidiaries located in middle-income countries where the green transition could otherwise be delayed by the adoption of a 'clean up later' model, waiting for the environmental Kuznets curve to set in (Stern, 2004; Pegels & Altenburg, 2020). Combining this finding with the result about host-country innovativeness, we can conclude that MNEs are pivotal in boosting subsidiaries' green innovative capacities in less developed countries with a high degree of general innovative capacity. Our quantitative evidence of this dynamic provides crucial support to some existing qualitative research, such as the study of the Indian subsidiary of a Danish supplier of wind-turbine blades mentioned earlier, which relied critically on access to skilled labor locally and knowledge interactions with the headquarters, which was located in the wind-power cluster in Denmark (Hansen et al., 2020). In the present paper, we have confirmed such qualitative insights from case-study research at a more aggregate level of analysis across various developing countries. These findings are encouraging given the urgency of transferring knowledge and innovative capabilities to actors in developing countries, which is necessary for them to engage in the green transformation of their economies.

We also add to the literature on sector specificity and the importance of inherent technological characteristics for the dynamics of green technologies (Huenteler et al., 2016; Schmidt & Huenteler, 2016). We do this by showing that MNEs specializing in different technologies display different patterns. Wind technologies diffuse more easily through MNE networks than solar technologies. This finding is somewhat counter-intuitive, given that solar power, as a highly mature technology, may be expected to involve greater mobility of knowledge. However, it is precisely because of the more tacit knowledge involved in the wind industry that knowledge transfer via MNEs, with dense global relationships inside the corporate network, has an important role to play in knowledge diffusion.

In addition, substantial local rootedness is also important for learning and knowledge diffusion to take place. This is shown by the greater technological advantage of M&As with respect to greenfield investments, confirming in the case of RE industries the general finding that entities with more local embeddedness (that is, joint ventures or acquisitions) are more innovative than newly established greenfield investments (Blomkvist et al., 2014).

5.1. Policy implications

Two key policy implications can be drawn from our findings. First, as green innovation systems need to be strengthened, countries with weaker green innovative capabilities can attract green FDI to enhance their innovative capacities to contribute to the green transition. Thus, national policy-makers need to target FDI specifically in the green technology sectors to strengthen their innovative capacities not only to adapt technologies to local conditions, but more importantly, to engage in innovation for developing new green solutions for the global market (Lema et al., 2020; Lema & Rabellotti, 2023; Yap & Truffer, 2019). Accordingly, as argued by Swilling et al. (2022), policy-makers should view the role of MNEs in the Global South more as a potential source of (green) industrial development than as a source of exploitation.[19] That said, policies aimed at attracting green FDI should go hand in hand with measures focusing on encouraging knowledge spillovers from MNE subsidiaries to domestic companies, such as policies including local content requirements, training of the local workforce and export subsidies, to make sure that the host economies benefit (Hansen et al., 2020).

Second, international organizations have a key role to play in strengthening green innovation systems. Increases in green innovative capacity benefit the global green transition and promote more technological variety in the market (that is, reducing the control of green technologies by a few advanced lead markets). It is high time that the issue of green technology transfers takes a more central role in the WTO around the TRIMS agreement so that policy frameworks reflect the public goods nature of green technology and support the global diffusion of green technology through FDIs. Furthermore, international organizations such as the UNFCCC should focus more on the importance of FDI as an important channel for low-carbon technology transfers. For example, in the technology needs assessments (TNA) undertaken under the UNFCCC in various countries with the aim of identifying specific green technologies of relevance (Haselip, 2021), there should be greater focus on the importance of enabling countries to attract FDI as mechanisms for technology transfer.

5.2. Issues for further research

The study leads to the identification of new research areas that should be addressed in the future. First, the focus on renewables as a cornerstone of the green economy, which is key to mitigating climate change, should be extended to other green technology domains, including energy efficiency technology and innovation in *hard to abate*, highly emitting sectors such as cement and steel (Öhman et al., 2022).

[19] While we agree with the authors that MNEs may be important sources of knowledge transfer, we would stress that the role of MNEs is multifaceted and that MNEs may often locate themselves in pollution havens or circumvent local environmental regulations (Nieri & Giuliani 2018).

Second, it will be important to investigate directly whether increased and improved green innovation in MNEs subsidiaries goes beyond them to generate positive green technological spillovers in the host countries. Generally, our results confirm long-standing research that MNE subsidiaries tend to outperform domestic firms in developing countries (see e.g., Saggi, 2002; Lall & Narula, 2004). Accordingly, green FDI seems to follow a broader pattern observed in the development studies literature. Importantly, however, while it is beyond the scope of this paper to assess whether and how MNEs contribute to the development of the host economies, numerous studies have shown that, although the extent of spillover may vary, it is likely that some degree of spillover will inevitably occur due to various mechanisms.[20]

Moreover, case-study research shows that technology and knowledge spillovers from green FDI takes place across various RE technologies and developing countries, including research on biomass power technologies in Malaysia (Hansen & Ockwell, 2014) and China (Hansen and Hansen, 2020), wind and solar in Kenya (Lema et al., 2018), and wind and solar in South Africa (Baker & Sovacool, 2017; Davy et al., 2021) and Mexico (Matsuo & Schmidt, 2019). Conversely, others have argued that, while spillovers from green FDI are not entirely absent, they can in some cases be limited (see e.g., Pueyo et al., 2011; Shen, 2018; Lema et al., 2021).

This article is an important first step, leading to future research aimed at generating an improved, robust, empirical understanding of the role of green FDI in transferring knowledge to developing economies through MNE subsidiaries, which may subsequently diffuse to domestic companies. To this end, we suggest that subsequent research could benefit from using our findings as a starting point for more systematic research that goes beyond case study research. As an example, one possible extension of the analysis could test the number (and quality) of green technologies co-patented by MNEs subsidiaries and domestic companies (de Araújo et al., 2019).

Third, there is a need to transcend patent analysis and identify additional indicators of green innovation, accounting for the different dimensions of technological characteristics that influence the dynamics of green technology transfer, such as the tradability of technology. While we suggest that this aspect of technology is a key factor in determining the dynamics of knowledge transfer, additional research is required to substantiate this finding. Such research is important in informing policy for accelerating the global diffusion of green technological knowledge.

Similarly, there is a need to improve understanding of the role of intellectual property rights regimes around these technologies. Intellectual property and global value chains for renewable energy technology are mainly concentrated in a handful of advanced countries: more international efforts are needed to globalize and speed up the green transformation. There is a mounting consensus regarding the need to treat green technologies, especially in renewable energy, as essential global public goods (United Nations, 2022). It is crucial to design knowledge-diffusion policies related to FDI in conjunction with both a technology-specific understanding of the diffusion dynamics and increased efforts to promote knowledge-sharing and technology transfers and remove the constraints of intellectual property. These are fundamental steps in ensuring support for the green transformation that will be imperative to present and future generations in both the Global North and the Global South.

CRediT authorship contribution statement

Vito Amendolagine: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Ulrich Elmer Hansen:** Funding acquisition, Conceptualization, Writing – original draft, Writing – review & editing. **Rasmus Lema:** Conceptualization, Writing – original draft, Writing – review & editing. **Roberta Rabellotti:** Funding acquisition, Conceptualization, Writing – original draft, Writing – review & editing, Supervision. **Dalila Ribaudo:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

Data availability

Data will be made available on request.

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.

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[20] These mechanisms include backward (and forward) linkages to domestic companies, labor mobility and demonstration effects (see e.g. Javorcik, 2004; Crespo & Fontoura, 2007, Morris et al., 2012; Arias et al., 2014).

Appendix

Table A1
Variables.

Variable	Definition	Source
FDI SUSBSIDIARY	Dummy variable that takes a value of 1 if the unit is an FDI and 0 if it is a domestic company	Orbis – Bureau Van Dijk
COUNTRY GDP PC	Gross Domestic Product over population (in log)	World Development Indicators
COUNTRY PATENT PC	Sum of the number of patent applications filed in the country from residents and non-residents (in log)	World Development Indicators
OIL RENTS (%GDP)	Difference between the value of crude-oil production at regional prices and the total costs of production	World Development Indicators
PATENT PORTFOLIO STOCK LAG 1	Number of INPADOC families applied by subsidiaries and domestic companies for up to one year before the investment (in log)	PATSTAT
ENVIRONMENT RELATED TAX REVENUE (% GDP)	Share of taxes on greenhouse gas (GHG) emissions reported in two components: an energy-related component (identified as energy tax) and a non-energy-related component, such as GHG emissions related to landfills or agriculture (identified as pollution tax)	OECDstat
AGE	Difference between the year of the investment and the company's incorporation date (in log)	Orbis – Bureau Van Dijk
MIDDLE SIZE	Dummy variable that takes a value of 1 if the company is medium-sized, 0 otherwise	Orbis – Bureau Van Dijk
LARGE SIZE	Dummy variable that takes a value of 1 if the company is a large company, 0 otherwise	Orbis – Bureau Van Dijk
EXCHANGE RATE	Annual exchange rate of the national currency against the US dollar	Penn World Table 10.0
LABOUR SHARE	Share of labor compensation in GDP at current national prices	Penn World Table 10.0
HUMAN CAPITAL	Human capital index	Penn World Table 10.0
LATITUDE	Distance from equator	CEPII
CHINA&INDIA	Dummy variable that takes value 1 if the host country is China or India, 0 otherwise	World Bank Country Classification
MIDDLE INCOME_NO_CHINA &INDIA	Dummy variable that takes a value of 1 if the host country is middle-income, except China and India, 0 otherwise	World Bank Country Classification

Table A2
Descriptive statistics: FDI subsidiaries.

Variable	Obs	Mean	Std.Dev.	Min	Max
FDI SUSBSIDIARY	1055	1	0	1	1
COUNTRY GDP PC	1055	2.744	1.396	−1.530	4.652
COUNTRY PATENT PC	1055	0.324	0.311	0	1.616
OIL RENTS (%GDP)	1055	0.741	1.837	0	36.814
PATENT PORTFOLIO STOCK LAG 1	1055	0.074	0.368	0	4.595
AGE	1055	0.481	1.058	0	4.977
MIDDLE SIZE	1055	0.197	0.398	0	1
LARGE SIZE	1055	0.681	0.466	0	1

Table A3
Descriptive statistics: domestic firms.

Variable	Obs	Mean	Std. Dev.	Min	Max
COUNTRY GDP PC	6276	3.216	1.112	−1.531	4.781
COUNTRY PATENT PC	6276	0.603	0.457	0	1.642
OIL RENTS (%GDP)	6276	0.491	1.674	0	54.496
PATENT PORTFOLIO STOCK LAG 1	6276	0.328	0.489	0	4.190
AGE	6276	2.378	1.075	0	5.262
MIDDLE SIZE	6276	0.310	0.462	0	1
LARGE SIZE	6276	0.260	0.439	0	1

Table A4
Alternative measure for company size.

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−0.370	0.244	0.295	0.777**	0.532	1.005***	1.496***	1.350***	−0.090	2.090***	1.263***	2.332***
	(0.346)	(0.324)	(0.316)	(0.307)	(0.326)	(0.360)	(0.467)	(0.382)	(0.436)	(0.425)	(0.452)	(0.416)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.964**	0.005	−0.344	0.063	0.100	0.160	−1.458***	−0.848***	−0.847***	−1.189***	−0.361	−0.496*
	(0.399)	(0.226)	(0.264)	(0.192)	(0.248)	(0.213)	(0.324)	(0.245)	(0.283)	(0.238)	(0.280)	(0.262)
AGE (LN)	−0.126	−0.289***	−0.173*	−0.237**	−0.135	−0.088	−0.082	−0.466***	−0.586***	−0.145	−0.322**	0.086
	(0.089)	(0.098)	(0.094)	(0.097)	(0.110)	(0.120)	(0.110)	(0.116)	(0.134)	(0.120)	(0.130)	(0.137)
COMPANY_SALES	−0.000*	−0.000	−0.000	−0.000	−0.000**	−0.000	−0.000**	−0.000*	−0.000	−0.000**	−0.000**	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
COUNTRY GDP PC (LN)	0.077	−0.081	0.105	0.309***	−0.126	0.007	0.175	0.284**	0.873***	0.920***	0.273**	0.326***
	(0.112)	(0.099)	(0.114)	(0.108)	(0.105)	(0.115)	(0.124)	(0.122)	(0.127)	(0.139)	(0.122)	(0.124)
COUNTRY PATENT PC (LN)	−0.090	0.586**	0.494**	0.616***	1.033***	1.252***	0.429	0.365	−0.060	−0.030	1.045***	0.410
	(0.216)	(0.247)	(0.226)	(0.220)	(0.256)	(0.284)	(0.278)	(0.324)	(0.308)	(0.259)	(0.345)	(0.333)
OIL RENTS (%GDP)	−0.035	−0.034	−0.040	0.004	−0.014	0.001	−0.071	−0.065	−0.077	0.096	−0.021	0.185*
	(0.059)	(0.051)	(0.058)	(0.053)	(0.047)	(0.072)	(0.056)	(0.066)	(0.051)	(0.092)	(0.049)	(0.112)
MANUFACTURING	0.817***	−0.303	−0.062	0.024	−0.040	0.103	0.117	−0.508*	−0.118	0.387	0.117	−0.337
	(0.233)	(0.239)	(0.245)	(0.208)	(0.233)	(0.247)	(0.269)	(0.289)	(0.284)	(0.309)	(0.303)	(0.323)
DEAL YEAR FE												
CONSTANT	−19.187***	−19.552***	−4.860***	−19.943***	−4.179***	−4.003***	−35.878	−32.519	−3.349***	−27.820	−5.667***	−2.934***
	(1.530)	(0.865)	(1.068)	(0.390)	(0.827)	(0.926)	.	(183439.334)	(1.075)	(56.224)	(1.280)	(0.792)
LNALPHA	2.637***	3.030***	3.176***	2.904***	3.265***	3.430***	4.175***	4.202***	4.310***	3.991***	4.123***	4.311***
	(0.188)	(0.127)	(0.140)	(0.133)	(0.152)	(0.141)	(0.097)	(0.104)	(0.107)	(0.107)	(0.111)	(0.124)
OBSERVATIONS	3738	3738	3738	3738	3738	3738	3738	3738	3738	3738	3738	3738

FDI subsidiaries = 709. # Domestic companies = 3,029. Robust standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

Table A5
Robustness test for additional host-country variables.

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−0.737***	0.031	0.277	0.509*	0.762***	0.740***	0.870**	1.027***	0.961***	1.615***	2.019***	1.959***
	(0.261)	(0.271)	(0.254)	(0.262)	(0.251)	(0.283)	(0.358)	(0.342)	(0.370)	(0.354)	(0.365)	(0.378)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.744**	−0.666***	−0.664***	−0.191	−0.532**	−0.223	−0.973***	−1.036***	−0.958***	−0.977**	−1.039***	−0.640***
	(0.323)	(0.177)	(0.224)	(0.146)	(0.211)	(0.165)	(0.179)	(0.163)	(0.238)	(0.392)	(0.236)	(0.242)
AGE (LN)	−0.318***	−0.264***	−0.182**	−0.231***	−0.076	−0.123	−0.212**	−0.432***	−0.336***	−0.188**	−0.152*	−0.087
	(0.071)	(0.073)	(0.073)	(0.075)	(0.072)	(0.088)	(0.083)	(0.077)	(0.085)	(0.089)	(0.093)	(0.102)
MIDDLE SIZE	0.087	0.213	0.075	0.134	0.097	0.881***	−0.027	−0.110	0.180	0.137	0.035	0.970***
	(0.162)	(0.181)	(0.175)	(0.179)	(0.209)	(0.217)	(0.198)	(0.216)	(0.223)	(0.249)	(0.248)	(0.267)
LARGE SIZE	0.344*	0.157	0.312	0.402**	0.392*	1.066***	−0.132	0.157	−0.323	0.059	0.550**	0.807**
	(0.186)	(0.198)	(0.200)	(0.189)	(0.200)	(0.237)	(0.223)	(0.237)	(0.227)	(0.257)	(0.257)	(0.330)
COUNTRY GDP PC (LN)	0.172**	0.047	−0.010	0.184**	−0.059	−0.047	0.086	0.423***	0.183	0.612***	0.301**	0.104
	(0.087)	(0.077)	(0.083)	(0.093)	(0.093)	(0.097)	(0.107)	(0.118)	(0.132)	(0.140)	(0.129)	(0.126)
COUNTRY PATENT PC (LN)	0.550**	0.857***	−0.067	0.232	0.398	0.787***	2.129***	1.490***	1.664***	1.031***	1.355***	2.084***
	(0.262)	(0.262)	(0.313)	(0.318)	(0.278)	(0.301)	(0.343)	(0.353)	(0.432)	(0.362)	(0.425)	(0.462)
OIL RENTS (%GDP)	0.043	0.016	−0.011	0.023	−0.014	0.097	−0.140**	−0.003	−0.211***	0.127	−0.031	0.172
	(0.045)	(0.040)	(0.043)	(0.051)	(0.041)	(0.061)	(0.057)	(0.051)	(0.066)	(0.079)	(0.049)	(0.139)
EXCHANGE RATE	0.000	0.000	0.001**	0.001***	0.000	0.001***	−0.002***	−0.001**	−0.002***	−0.000	−0.001***	−0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
LABOUR SHARE	8.887***	6.896***	4.577**	7.745***	0.431	7.622***	5.664**	11.132***	−0.559	13.316***	3.988	5.178*
	(2.033)	(1.703)	(1.889)	(2.232)	(2.242)	(2.007)	(2.324)	(2.430)	(2.900)	(2.637)	(2.664)	(3.079)
HUMAN CAPITAL	−0.527*	−0.208	0.301	−0.096	0.330	−0.075	−0.429	−1.289***	−0.520	−1.200***	−0.424	−0.266
	(0.280)	(0.271)	(0.304)	(0.315)	(0.327)	(0.318)	(0.341)	(0.379)	(0.443)	(0.442)	(0.462)	(0.419)

Table A5 (*continued*)

	OUTPUT: # green patents						**OUTPUT: # forward citations to green patents**					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
LATITUDE	0.010*	0.004	0.004	0.006	0.003	0.004	0.008	0.018***	0.017**	0.010	0.002	0.008
	(0.006)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.008)	(0.008)
INDUSTRY FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−24.217***	−25.564	−24.928***	−26.147***	−21.471	−25.234***	−23.002***	−26.018	−30.551	−25.460***	−24.013***	−25.240
	(2.276)	.	(5.702)	(2.378)	.	(1.448)	(1.570)	.	.	(1.600)	(1.547)	.
LNALPHA	2.399***	2.811***	2.753***	2.830***	2.973***	3.150***	3.950***	4.022***	4.068***	3.914***	3.996***	4.098***
	(0.167)	(0.102)	(0.109)	(0.116)	(0.112)	(0.109)	(0.071)	(0.072)	(0.081)	(0.083)	(0.084)	(0.098)
OBSERVATIONS	7326	7326	7326	7326	7326	7326	7326	7326	7326	7326	7326	7326

FDI subsidiaries = 1,051. # Domestic companies = 6,275. Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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