Unlocking the green door of local development: MNEs and regional specialization in environmental technologies

Davide Castellani[♣] Giovanni Marin[♦]
Sandro Montresor[♥] Antonello Zanfei[♠]

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Abstract

The paper builds on insights from eco-innovation and international business studies to investigate the effects of MNEs on regional specialisation in green technologies. Combining the OECD-REGPAT and the fDi Markets dataset with respect to 1,305 European NUTS3 regions over the period 2003-2014, we find that the multinational presence is associated with the regional propensity to specialize in green-tech when FDIs occur in industries that are cognitively proximate to the environmental technology at stake. In addition, we show that R&D FDIs in transport are conducive to revealed green-technological advantages in transportation industries, while it is non-R&D FDIs in energy that stimulate innovation in energy industries. Moreover, our findings suggest that cognitively proximate FDIs can contribute to breaking up path dependent patterns of specialization, by helping regions to switch from non-green to green in the case of energy industries; while they facilitate the persistence of specialization of regions that are green already in the case of transport industries.

Keywords: green regional specialisation; MNEs; FDIs; environmental innovation.

[♣] Henley Business School, University of Reading, UK; Mail address: Whiteknights Campus, RG6 6UD, Reading (United Kingdom); Email: davide.castellani@henley.ac.uk
[♦] Department of Economics, Society, Politics, University of Urbino, Italy; Mail address: Via Saffi 42, Urbino (Italy); Email: giovanni.marin@uniurb.it
[♥] Faculty of Economics and Law, Kore University of Enna, Italy: Mail address: Cittadella Universitaria, Enna (Italy); Email: sandro.montresor@unikore.it
[♠] Department of Economics, Society, Politics, University of Urbino, Italy; Mail address: Via Saffi 42, Urbino (Italy); Email: antonello.zanfei@uniurb.it

1 Introduction

Environmental sustainability is nowadays an inescapable priority, giving rise to a mounting concern for the development of "green technologies". While early studies paid little attention to spatial aspects of the generation and diffusion of such technologies (Truffer and Coenen, 2012), recent albeit exiguous research has emphasized the regional dimension of environmental innovation (EI) (Cooke, 2011; 2012; Gibbs and o'Neill, 2017). In fact, EIs pay a key role in the latest studies on the regions' capacity to diversify their technological profile over time (Santoalha and Boschma, 2019). Moreover, other streams of empirical research have focused more and more on factors affecting green inventive activity at the regional level (Barbieri et al 2016, Horback 2014).

This paper investigates the role of Foreign Direct Investments (FDIs) and the activities of multinational enterprises (MNEs) in helping to explain the regional development of green technologies. Indeed, research on the impact of FDIs on the green inventive activities of regions appears to be rather scanty and mainly conducted by means of context specific analyses (Cainelli et al., 2012; Chiarvesio et al., 2014). Thus, there is ample room for investigation in this domain. In particular, the following gaps can be identified in empirical research:

a) *Scarcity of generalizable evidence on the impact of MNEs on local EI*. Extant empirical works are mainly based on case-studies or ad-hoc surveys, yielding hardly comparable results, and which however offer partial and indirect evidence on the role of FDIs in local EIs. Systematic empirical work is necessary to ascertain their actual impact on local EI, and whether the observed effects persist when controlling for different regional characteristics and multinational strategies;

b) *Lack of analyses on the MNEs' impact on the technological domains of EI*. To the best of our knowledge, there is no systematic research on which environmental technologies are most affected by FDIs, either directly through the EI activities of foreign affiliates, or indirectly, i.e. through spillover effects on green innovation of local firms.

c) *Missing research on how FDIs affect changes in the green specialization of regions over time*. While there are several accounts of green specialization patterns at the regional level (Tanner, 2016; Santoalha and Boschma, 2019; Montresor and Quatraro, 2019), there are a few systematic studies on how FDIs affect such patterns. As a result, there is scarce evidence on whether and how FDIs contribute to the switch from non-green to green specialization of local production systems. This undermines the possibility of evaluating the actual contribution of multinational presence to the transition of regions towards sustainable development.

This paper tackles the above-mentioned research gaps. Using data on a sample of 1,305 European NUTS3 regions over the period 2003-2014, for which we merge OECD-RegPAT with the fDI market dataset, we add to extant empirical research in three ways.

First, consistently with views of localized technical change and with recent literature on the geography of innovation, we show that the effects of multinational presence on regional EIs are greater when FDIs occur in sectors characterized by some degree of "cognitive proximity" to a given green technology. Although some differences do exist in the impact of FDIs according to the industries in which they take place, it appears that the impact of FDIs across knowledge fields is nearly negligible, and MNEs generally contribute to EI within the boundaries of the domains in which they invest. Second, we show that the nature of FDIs does matter in determining the impact on local green-tech specialisation. In fact, it does make a difference whether foreign investments concern R&D activities or not. However, this distinctive impact of R&D and non-R&D FDIs is likely to be mediated by the characteristics of industries in which FDIs occur, and of environmental technologies at stake. Third, we provide evidence on how FDIs affect, and eventually contrast, the path-dependence of regional specialization in environmental technologies over time. In particular, we illustrate that FDIs may attenuate path-dependent specialization patterns in specific environmental technologies.

The rest of the paper is structured as follows. Section 2 positions the paper across the different streams of literature it relates to. Section 3 illustrates the empirical application, and Section 4 discusses the results. Section 5 concludes.

2 Background literature and research questions

Although initially developed in a-spatial framework (Horbach et al., 2012), the analysis of green technologies and eco-innovations (EIs) has been recently enriched of several regional characterizations. On the one hand, the literature on technological diversification has shown that also green technologies develops in a path- and place-dependent way, and it is conditioned by the exiting regional knowledge-base (Van den Berge and Weterings, 2014; Tanner, 2016; Barbieri et al., 2018; Colombelli and Quatraro, 2019; Corradini, 2019; Barbieri and Consoli, 2019; Montresor and Quatraro, 2019). On the other hand, research on the determinants of EIs has shown that their unfolding is affected by several region-specific features, including agglomeration vs. variety/relatedness economies (Antonioli et al., 2016; Horbach, 2014); the availability of science and research centers, skilled human capital and suitable financial mechanisms (Horbach, 2014; Arranz et al., 2019); public awareness of environmental issues and the characteristics of policies targeting local sustainability (Santoalha and Boschma, 2019; Giudici et al., 2019).

Some studies have also emphasized the role played by foreign investors as drivers of regional EI. In fact, it is argued that MNEs, through their local subsidiaries, may affect the development and adoption of green technologies in the regions in which they are active (Cainelli et al., 2012, Chiarvesio et al., 2014). However, the evidence produced is still context-specific and is mainly based on ad-hoc surveys, making results hard to generalize.

Given the paucity of extant research on the impact of FDIs on EI at the sub-national (regional) level, it is worth referring eclectically to the more general literature on direct and indirect effects of FDIs on environmental sustainability. The aim is to derive useful insights, and shed more light, on the mechanisms through which MNEs can affect the local development of green technologies.

As for *direct effects* of FDIs, several studies have documented that subsidiaries of foreign MNEs are generally more innovative than domestic-owned firms (Castellani and Zanfei, 2006, Guadalupe et al., 2012, Stiebale, 2016), so that their presence *per se* augments the knowledge base of host economies. Direct effects are likely to be higher in the case of R&D FDIs as these represent an injection of innovation capacity for the recipient country or region.

A rather limited literature has addressed the internationalization of R&D and innovation in the specific area of environmental technology. While these works do not generally focus on regions as destination economies, they highlight some important mechanisms underlying EI offshoring decisions, which may in turn contribute to changes in the knowledge base of host economies in general and of regions in particular. Some contributions use case-studies or ad-hoc surveys to explore EI activity undertaken by MNE subsidiaries in some specific host locations, generally focussing on one or a few countries of origin or destination (Aguilera-Caracuel, et al. 2012; Tatoglu et al. 2014; Kawai et al. 2018). Other works look at multiple patent filings to proxy technology transfers across national borders (Dechezlepretre et al.2015; Dekker et al., 2012). Only a few examine specifically the internationalization of green innovation using proxies of cross-border patenting activities (Noailly and Ryfisch, 2015, Marin and Zanfei, 2019). Although using different methods, most contributions find that environmental regulation positively impacts on international transfer of green technology. Institutional proximity, induced by coordination between source and destination areas, is also found to facilitate internationalisation of green technology (Carraro and Topa, 1994; Beise and Rennings, 2005; Costantini et al. 2017). Nevertheless, there are some divergences on the actual balance between compliance costs, that favour location where regulation is less stringent, and technological and demand opportunities associated with the introduction of binding pollution abatement policies (Zugravu-Soilita, 2015; Marin and Zanfei 2019). Stakeholder pressures are also found to affect green innovation by inducing the implementation of formal environmental management systems (EMS), which will eventually facilitate the local adoption and generation of green innovation (Kawai et al. 2018). Similar to studies on R&D offshoring in other contexts, Hascic et al.(2012) and Noailly & Ryfisch (2015) also indicate that cross-border EI is favoured by absorptive capacity of recipient countries, by strong IPRs, and by geographical proximity

As far as *indirect effects* are concerned, FDIs are acknowledged to foster innovation activities in domestic firms. Such indirect effects have been by and large analysed in terms of knowledge spillovers generated by MNEs through a number of channels including: competitive pressures inducing domestic firms to innovate; voluntary and involuntary technology transfer from MNEs to local firms; labor market externalities and effects on the quality of human capital in the host economy; backward and forward linkages generating opportunities for local firms to obtain static and dynamic economies of scale (Castellani et al 2015; Crescenzi et al., 2015; Javorcick et al., 2018). Empirical analyses carried out within this stream of literature seldom focus on the effects of FDIs on EIs. However, they highlight different circumstances under which such indirect effects take place, which may have implications for the analysis of green innovation as well. In particular, it has been noted that the importance of the above mentioned channels and the intensity of spillovers largely depend inter alia on: the ex-ante competitive conditions in the market; the technology gap separating investors and local firms (Findlay 1978, , Griffith et al. 2006); the level of absorptive capacity in the host economy (Cantwell 1989; Kokko et al. 1996); the capacity of host economies to offer a sufficient variety and quality of inputs to investing firms (Rodriguez-Claire 1996); the nature and motivation of FDIs (Le Bas and Sierra, 2002).

A few empirical studies have provided evidence on spillovers effects of FDIs in the specific case of EI, accruing either through user-producer relationships along the value-chain (Albornoz et al., 2009), or through horizontal demonstration effects of environmental technologies/policies in the home country (Dechezleprêtre and Glachant, 2014). These studies confirm that also in the domain of green technology, spillovers are conditioned by the absorptive capacity and human/managerial capital of local firms, and by the kind of strategy MNEs follow in entering the foreign market (Rezza, 2013; Tang, 2015).

To summarize, the existing literature converges to highlight a potentially important role of MNEs for local innovative activities in general and for EI in particular. Although most of these studies refer to different fields of activity, other than the domain of green technologies, and most often refer to the national level, they shed some light on the channels through which FDIs may directly or indirectly affect local development and adoption of environmental technologies. However, there are several areas in which research on the effects of FDIs on EI is still largely under-developed. We shall concentrate on three such areas.

The first one concerns the *technological domain of FDI effects*. The issue at stake is whether MNEs, through the innovative activities of their affiliates and via their knowledge spillovers, can contribute to determine which green technologies are developed in the regions where they are active. This issue connects to recent research which has much emphasized past and place dependence in shaping local patterns of technological development. In particular, relatedness literature has suggested that such patterns are heavily conditioned by the characteristics of the knowledge base that regions have accumulated over time (Boschma 2005, Essletzbichler and Winther, 1999; Neffke et al., 2011;Boschma et al., 2013). This view has emerged also in studies showing that the green diversification of regions occurs mostly in related knowledge fields (Tanner 2016; van den Berge and Weterings 2014; Corradini 2019; Santoalha and Boschma, 2019)

One may suggest that also when considering the impact of FDIs, cognitive proximity matters. That is, industries in which FDIs occur reflect the combination of local knowledge base with MNEs' competencies and capabilities of operating abroad (Le Bas and Sierra 2002, Patel and Vega 1999). The cognitive distance between the industry in which FDIs occur and the knowledge fields characterizing a given environmental technology determines the scope for the effects the inward FDIs could have on EI at the regional level, being this larger in case of higher cognitive proximity. Just to make an example, the extent to which inward FDIs affect the regional capacity to specialize in transport-related environmental technologies (e.g. technologies for smart and sustainable mobility) is expectedly greater if MNEs invest in the transport sector, by adding knowledge that could be directly functional to the regional development of the related technologies.

In principle, positive effects could be expected to accrue also from FDIs in sectors that are less cognitively proximate. With respect to the previous example, FDIs in energy might facilitate innovation in fuel technology, which represents a crucial input for the introduction of sustainable transports. In this case, we would observe some degree of "technical proximity" (e.g., in terms of input-output coefficients) between energy generation and transport manufacturing, hence FDI in the former may lead to innovation in the latter (or viceversa). The latter view is consistent with the Windows of Localisation Opportunities approach put forth in the late 1980s, which suggested that the emergence of new industries is rather independent of pre-existing industrial structures. The idea is that an emerging industry, characterised by radically new technologies and drastic innovation, has such unique requirements that any pre-existing locational conditions will be unlikely to satisfy these requirements (Storper and Walker, 1989). The exploitation of these windows of opportunity does require some background knowledge that is consistent with the new technological patterns and may result from innovative combination of existing knowledge assets (Tanner 2016). However, FDIs and the activities of foreign subsidiaries may provide key knowledge inputs and combination abilities that facilitate technological diversification.

Whether FDIs contribute to EI in cognitively proximate technological domains, or in more distant technological domains is the result of the nature and characteristics of technologies, and of multiple interactions and tensions between the strategies and behaviour of MNEs and of local firms and institutions, making it hard to draw clear predictions in this respect. This leads us to formulate the following Research Question:

RQ1: *To what extent does proximity condition the impact of FDIs on the green tech specialisation of regions?*

The second research area that needs to be explored refers to the kind of *business activity in which FDIs occur*. When we refer to the regions' capacity of specializing in technologies (as for example revealed by their inventive activities), the international business activities that most affect it are arguably those related to Research and Development (R&D). Indeed, R&D FDIs are likely to provide both a higher direct contribution to local innovation (Belitz and Mölders 2016; Castellani and Zanfei, 2006; Dachs and Peters, 2014; Griffith et al., 2004) and a potential for significant spillovers on the innovation of local firms (Feinberg and Majumdar, 2001; Braconier et al., 2001; Castellani and Zanfei, 2006; Cheungk and Ping, 2004; Fu, 2008; Giroud et al. 2012; Ha and Giroud, 2015; Marin and Sasidharan, 2010; Todo, 2006).

However, two caveats apply when the effects of R&D FDIs in green domains are considered. First, there is a high heterogeneity in the dynamics and composition of the knowledge bases that characterize different environmental technologies. To illustrate, while fuel cell technology, mainly applied in automotive industries, is perceived as a radical innovation and builds on a complex knowledge base (Tanner 2016), it is much less so in the case of membrane bioreactor technology, used in water waste management activities (Binz et al. 2014). Hence R&D FDIs are likely to play a very different role in shaping eco-innovation in the two cases. Second, we have shown that, when it comes to exploring the effects of R&D FDIs on green technologies, empirical research has so far used either case-studies and ad-hoc surveys, thus yielding hardly generalizable results; or rather indirect proxies of R&D internationalization, based on cross-border patenting activities. There is thus a need for more systematic empirical analysis referring to different industries and based on FDI data at the functional level rather than on indirect measures of the internationalization of innovation, to assess the actual impact of R&D investment inflows on EI innovation.

Based on these arguments it is worth addressing the following Research Question:

RQ2: *To what extent do R&D FDIs drive regional specialisation in green technologies?*

The third research area that we address concerns the role that MNEs can have in driving the regions' *capacity of substantially diversifying their technological repertoire over time* and eventually change their economic structure. Achieving a new revealed comparative advantage in the introduction of green technologies, hence switching from a non-green to a green-tech regional specialisation, can actually be retained as a special case of technological diversification. While benefiting from the relatedness to the extant regional activities (Santoalha and Boschma, 2019; Montresor and Quatraro, 2019), a switch to green specialisation could require and entail an important degree of structural change. In spite of its possible cumulativeness, the greening of regional technologies does actually imply a shift towards a new techno-economic paradigm and the adoption of alternative patterns of industrialisation (Hayter and Le Heron, 2018). Without referring to the green domain, recent research has shown that MNEs (and foreign-owned firms) act as a powerful leverage for these processes of regional diversification and structural change: on the one hand, by injecting in the region outer knowledge that makes it deviate from its capabilities more than domestic firms do (Elekes et al., 2019); on the other hand, by reshaping the set of (forward) production linkages of the hosting region and affecting its degree of industrialization/tertiarization (Ascani and Iammarino, 2018). Through a further green extension of this latter argument, we formulate our third and last research question:

RQ3: *To what extent do FDIs favour the shift from non-green to green regional tech specialization?*

3 Empirical analysis

3.1 Data

The previous research questions are addressed through an econometric investigation of 1,305 EU regions (NUTS 3 level). To do so, we combine information over the period 2003-2014 from the OECD-REGPAT, fDi Markets (fDi Intelligence, Financial Times), and from the Eurostat regional statistics database.

From the OECD-REGPAT database we retrieve the number of patent applications made at the European Patent Office (EPO) by the inventors that reside in each and every NUTS3 EU region.[1] While subject to several limitations (see Griliches, 1990), patent data have been shown to represent a reliable measure of the regional production of new technological knowledge (Acs et al., 2002), and will be thus used to calculate the specialisation of regions in green technologies (see Section 3.1). In this last respect, patents have also been argued to be the handiest way to measure EIs, given the availability of narrowly defined patent classes (according to the International Patent Classification - IPC - and the Cooperative Patent Classification - CPC) to inspect the environmental nature of the technology at the basis of the patented invention. Following this rationale, we have identified (regional) green patents according to the classification recently put forward by the 'OECD-ENVTECH indicator' (Haščič and Migotto, 2015). In brief, regional patents have been attributed to a specific environmental technology if they report at least one CPC or IPC through which the classification identifies the relative field. The OECD-ENVTECH indicator actually groups environmental technologies into 9 macro-categories (see Table A1 in the Appendix), out of which we consider the three major groups of such technologies, which account for over three-quarters of all green patents:[2] i) environmental management technologies; ii) climate change mitigation technologies

[1] We allocate patents to the NUTS 3 region of residence of the inventor, sorting them by priority date. Inventors have been chosen instead of assignees given that patents developed in a specific location could be assigned, for internal strategies, to the headquarter of the company or to the ultimate owner, making the address of the assignee a poor proxy of the location of the development of the invention.

[2] The OECD did not publish yet the list of specific technologies and corresponding IPC/CPC classes for group 3, related to "Biodiversity protection and ecosystem health". On the other hand, due to the small number of patents belonging to groups 2, 5 and 8 (overall, 0.96% of all patents), we have attributed these three small categories to the first group of "Environmental management". These three groups actually focus on technologies dealing with environmental problems once they occur (as environmental management technologies) rather than on their prevention.

related to energy generation, transmission or distribution; and iii) climate change mitigation technologies related to transportation. Considering that the year 2014 is the latest one with respect to which patent data can be obtained with no (or little) risk of data-handling truncations due to delayed publication of patent applications, and cumulating them across 4-year temporal windows to attenuate their erraticism, Figure A1 (in the Appendix) reports the trend in the share of these three classes of environmental patents in EU regions. Heterogeneous patterns clearly emerge across classes of environmental patents, thus suggesting that we should deal with green technologies in a disaggregated way.

From the fDi Markets database we retrieve the number of FDI projects that, with respect to each and every year from the first available (2003), have been 'announced' as located in a certain city and, using its longitude and latitude, we attribute them to the correspondent NUTS3 European region.[3] In order to test for the cognitive proximity between FDIs and green-technologies, we have referred to the classification that fDi Markets provides of foreign investment macro-sectors (or 'industry clusters') and tried to identify among them what the OECD (Golub et al., 2011) calls "environmentally relevant FDIs", as "investments in sectors where the scope for environmental spillovers is greatest" (Greeninvest, 2017, p. 14). Looking at the available fDI Markets' 'industry clusters', we have thus searched for those marked by the highest opportunities for green innovation, and singled out the following three groups of environmentally-sensitive industries: i) environmental technology; ii) energy; and iii) transportation (transport equipment, transportation, warehousing and storage). Indeed, EI opportunities are high in these industries for different reasons. On the one hand, energy and transportation industries are particularly exposed to pressures to reduce pollution and/or consumption of natural resources, inducing firms to carry out R&D in specific directions, and generating a high "derived demand" for green innovation. On the other hand, environmental technology industries face a very dynamic demand for pollution abatement equipment and devices from all sectors, thus enhancing EI..[4] FDIs in all other industries

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[3] fDI market is actually an event-based (or deal-based) database, whose entry is a project, for which the provider reports information from several publicly available information sources.

[4] While arbitrary to a certain extent, the identification of these environmentally relevant FDIs has two advantages with respect to other configurations of "green FDIs" elaborated so far (see Greeninvest, 2017, for a survey). First of all, it does not force us to be as much arbitrary in elaborating alternative clusters with respect to those the focal dataset already identifies. Second, their sectoral boundaries are wider and

are considered in a residual category, which we consider to have lower EI opportunities. Figure A2 (in the Appendix) reports the composition of these environmentally relevant FDIs received by EU regions (including within-EU FDIs) for three 4-year temporal windows of our focal period (2003 to 2014). Overall, these FDIs account for about 23% of all inward FDIs in the same period, with transportation representing the largest share (15% of all projects), and with energy and environmental technology counting for about 2.5% and between 2% and 5%, respectively. As Figure A2 (in the Appendix) shows, the different volumes of FDIs in these environmentally-sensitive industries reflect also a difference in geographical dispersion. While 46% of EU regions actually received at least one FDI in transport, FDIs in environmental technologies and energy are relatively more geographically concentrated in 30% and 18% of EU regions respectively.

By cross-classifying technologies and FDIs, we propose a correspondence based on the level of cognitive proximity between the resulting nine environmentally-sensitive FDIs and green-technology pairs (Table 1). In response to RQ1, we test whether and to what extent the effects of FDI on green-tech regional specialization are greater in those pairs where the cognitive proximity between the two is the greatest, that is, in those marked with an X in Table 1.

Table 1 – Green technologies vs. environmentally relevant FDIs: proximate pairs

	Green technologies		
		Climate change mitigation technologies related to:	
Environmentally relevant FDIs in:	1. Environmental management technologies	2. Energy generation, transmission or distribution	3. Transportation
i. Environmental technology	X		
ii. Energy		X	
iii. Transportation			X

encompass more than the limited number of FDIs for which environmental sustainability is a dedicated target. In addition, it might be worth observing that UNCTAD (2010) identifies "Green FDIs" with those occurring in three key business areas: renewable energy, recycling activities and low-carbon technology manufacturing, which partially overlap with the ones included in the three fDiMarkets "industry clusters" we focus on in this paper.

Still with respect to the identified environmentally relevant FDIs, in order to respond to RQ2, from fDi Markets we control whether foreign investments occur in R&D activities or in other activities (such as mainly production and sales activities) and identify regions receiving at least one FDI in R&D and those receiving at least one FDI in non-R&D activities. Finally, to address RQ3, we check the extent to which a switch from non-green towards green specialization of regions takes place over the examined period.

3.2. Variables and econometric strategy

Following the extant literature, the technological specialisation of the region is identified by using green patent data to build up a Revealed Technological Advantage (RTA) indicator (Le Bas and Sierra, 2002) as follows:

$$GreenRTA_{ijt} = \frac{PAT_{ijt}}{\sum_{i=1}^{n} PAT_{ijt}} \Bigg/ \frac{\sum_{j=1}^{m} PAT_{ijt}}{\sum_{i=1}^{n}\sum_{j=1}^{m} PAT_{ijt}} \tag{1}$$

where PAT_{ijt} is the number of (EPO) patent applications in the environmental technology *j*, made by inventors that reside in region *i* at time *t* (where t denotes a 4-year time window, in the period 1979-2014). As with respect to the standard indicator of revealed comparative advantages, region *i* is (is not) specialized in technology *j*, if $GreenRTA_{ijt}$ is larger than 1 (in between 0 and 1), as the region is patenting relatively more (less) in the green technology *j* compared to other regions.

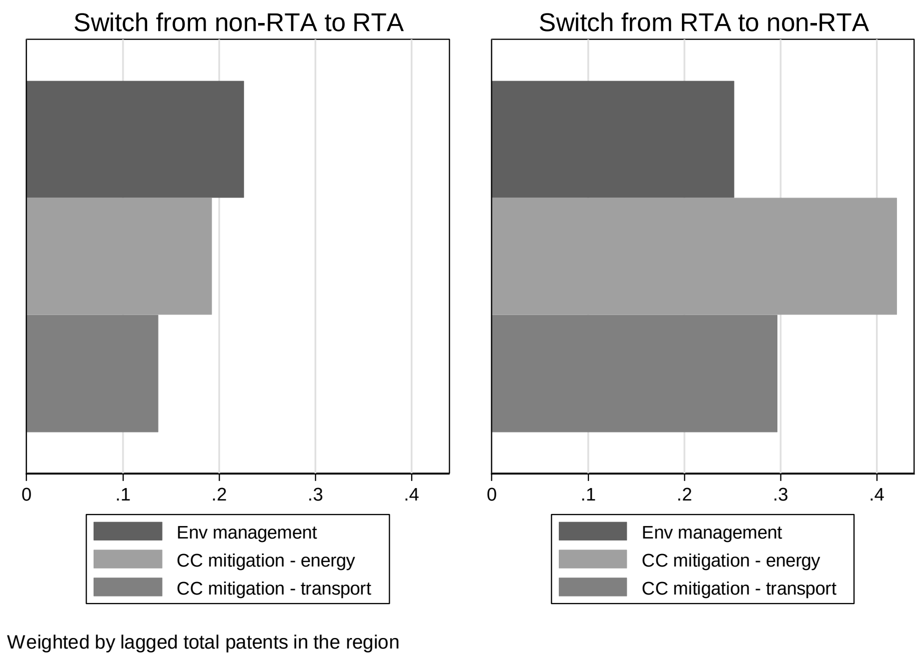
While $GreenRTA_{ijt}$ is a continuous variable (with 0 as lower bound), our main interest is for the role of FDIs in driving the region capacity to acquire a comparative advantage over time in the development of green technologies. Accordingly, our focal dependent variable, $GreenSpec_{ijt}$, is a discrete version of $GreenRTA_{ijt}$: a dichotomic one, which measures whether region *i* is (value 1) or not (value 0) specialised in a certain green technology *j* in period *t*. [5] More precisely, consistently with our identification strategy, in the econometric regressions we will consider three different specifications of this

[5] As a robustness check, we also consider a more demanding threshold of 1.5 to define specialization (Table B1). This means that a region is considered as 'specialized' if its share of environmental patents over its total patents is 50% larger than the world average.

variable, by referring j to environmental management technologies, climate change mitigation technologies related to energy, and to transport, respectively.

As Figure 1 shows (left-hand panel), over the period 1979-2014 about 15-20% of non-specialized regions switched to green specializations.[6] On the other hand, as many as 25-45% of green-specialized regions have de-specialized over the same period (Figure 1, right-hand panel). This suggests that the transition to a green-tech revealed advantage is not irreversible and that maintaining it over time is a regional capacity that also deserves attention, as distinguished from that of acquiring it.[7]

Figure 1 – Share of regions that switched in their environmental RTA (1979-2014, 4-year time windows)



As far as the explanatory variables are concerned, our focal regressors are three binary indicators, $Env\ FDI_{irt}^{0,1}$, which indicate whether, in period t, region i has received at least one FDI project in industry r (where r denotes environmental technology, energy or transport industry clusters). As we said, a fourth dummy for FDIs occurring in all of the

[6] Results are based on 4-year time windows from 1979 to 2014 and are weighted according the total number of patents by regional resident inventors in the starting period.

[7] It is worth mentioning that the number of regions that were not specialised is much higher that the number of regions that were specialised in environmental technologies. Hence, the smaller percentages in the left panel actually correspond to a much larger number of regions.

other industries is also considered. In investigating the role of these focal regressors, we first of all control for the size (number) of inward FDI projects received by region *i* in period *t*,[8] for its economic size in terms of GDP_{it} (average over time and in log, from Eurostat), and its relative technological importance within its country, by retaining its share of the country's patents. We also consider the regional availability of knowledge in Key Enabling Technologies (KETs), which have been found crucial in driving green technological specialisation (Montresor and Quatraro, 2019). More precisely, we control whether the focal region had, at *t* - 1, a revealed technological advantage in one of the six technologies of this kind: nano and micro-electronics, nanotechnology, industrial biotechnology, advanced materials (e.g. photovoltaics, advanced batteries), photonics, Advanced Manufacturing Technologies (e.g. thermal, laser, ...), following their IPC/CPC classifications proposed by the European Commission (2012).

Basic descriptive statistics for our variables of interest are reported in Table 2.

Table 2 – Basic descriptive statistics

Variable	Mean	Std dev	Min	Max
log(GDP)	8.5344	1.0720	2.2513	12.2281
RTA in KETs (dummy)	0.4416	0.4966	0	1
Region's share of country patents	0.0045	0.0160	0	0.3049
No inward FDI (dummy)	0.4501	0.4976	0	1
Number of inward FDI (log)	0.8266	1.2045	0	6.3936
FDI in env tech cluster (dummy)	0.1459	0.3530	0	1
FDI in energy cluster (dummy)	0.0931	0.2906	0	1
FDI in transport cluster (dummy)	0.3028	0.4595	0	1
FDI in other clusters (dummy)	0.4976	0.5001	0	1
RTA in envirnomental management (dummy)	0.4113	0.4921	0	1
RTA in CC mitigation technologies related to energy generation, transmission or distribution (dummy)	0.3412	0.4742	0	1
RTA in CC mitigation technologies related to transportation (dummy)	0.2094	0.4070	0	1
RTA in CC mitigation technologies related to buildings (dummy)	0.2312	0.4216	0	1
RTA in CC mitigation technologies in the production or processing of goods (dummy)	0.3177	0.4656	0	1

[8] About 55% of region-period pairs show at least one inward FDI. To account for the many zeros in the count of FDI projects, we include both a dummy variable (=1 if the region did not receive any inward FDI in the period) and the logarithm of the count of inward FDI. We arbitrarily set to zero the variable that considers the logarithm of inward FDIs when the count was zero to ease the interpretation. Accordingly, the coefficient of the dummy variable 'No inward FDI' should be interpreted as the difference in the probability of being specialized between regions with zero FDIs and regions with one inward FDIs (log(FDI=1)=0); the coefficient of the log(FDI) should be interpreted as the relationship between log(FDI) and the probability of being specialized for regions with a strictly positive number of inward FDIs.

Using the previous set of variables, our baseline specification is a probit estimation of the following model:

$$GreenSPEC_{iit}^{0,1} = \phi\left(\alpha + \sum_{r=1}^{4}\gamma_r \, Env\ FDI_{irt}{}^{0,1} + X'_{it,t-1}\theta + \lambda_c + \tau_t + \varepsilon_{it}\right) \qquad (2)$$

where $X'_{it,t-1}$ is the vector of our controls for unobserved heterogeneity, λ_c a series of country dummies to account for country-level unobserved features, τ_t a battery of time-dummies to capture generalised shifts in inventive activity in green technologies, and ε_{it} an error term with standard properties.

To account for time-invariant unobserved heterogeneity in equation 2 in a flexible way, we plug among the regressors the pre-sample mean of our dependent variable measured in the period 1979-2002 (see Blundell, Griffith and Windmeijer, 2002, for an illustration of this methodology).[9] The idea is that the pre-sample mean is a good proxy for the time-invariant individual (i.e. region) fixed effect.[10]

As illustrated in Table 1, we expect there be a correspondence, in terms of cognitive proximity, between the values of *r* and *j* of our focal variables. We will exploit this correspondence to respond to RQ1 about the role of cognitive proximity. In particular, we will check whether and to what extent FDIs in sectors related to environmental technologies, energy and transport are associated with a technological specialization in environmental management technologies, climate change mitigation technologies related to energy or transportation, respectively. We will also check the role of the R&D FDIs (RQ2) by substituting $EnvFDI_{irt}^{0,1}$, with two dummy variables, $EnvFDI_{irt}^{R\&D;0,1}$ and $EnvFDI_{irt}^{Non\text{-}R\&D;0,1}$, which identify whether environmentally related FDIs in sector *r* involve R&D activities or not, respectively.[11]

Finally, in order to respond to RQ3 and check the role of our focal FDIs in helping the region gain a revealed technological advantage in the green domain, in case it does not

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[9] As a robustness check, we also use pre-sample mean for the period 1979-1994 to limit possible endogeneity concerns, see Table B3 (in the Appenidx). Results remain robust.

[10] To further account for unobserved heterogeneity, we also estimate our model with the probit random effect estimator, see Table B4. We do not observe any substantial difference in our main results.

[11] In order to capture the technological nature of FDIs to a large extent, we have considered in R&D those FDIs that have occurred both in "research and development' and in "design, development and testing". Results are robust when R&D is considered *strictu sensu*.

have it already, we re-estimate equation (2) by substituting $EnvFDI_{irt}^{0,1}$, with two dummy variables, $EnvFDI_{irt-1}^{spec;0,1}$ and $EnvFDI_{irt-1}^{non\text{-}spec;0,1}$, taking value 1 if region *i* was specialised (or not) in technology *j* in the period *t*-1.

4 Results

Results for the baseline estimation of equation (2) are reported in Table 3. Starting with our controls, we observe that, with the weak (significant) exception of that in energy related technologies, larger regions do not have a larger chance to specialise in the green technologies at stake. Similarly, a specialisation advantage is not revealed either by the 'technological-champion' regions of the country (in terms of national patent shares), suggesting that greening the knowledge base could not represent a further divide with respect to peripheral ones. Quite interestingly, when the specific domain of green technologies is disentangled, regionally available KETs appear to have a more circumscribed effect than that detected by previous work on environmental technologies at large (Montresor and Quatraro, 2019). The combinatorial properties of these General Purpose kind of Technologies (GPTs) appear to favour only the specialisation in energy-related ones, pointing to a possible knowledge distance with respect to the other two green-techs, which deserves to be investigated in future research.

As far as our focal controls are concerned, let us first notice that the number of inward FDIs in the region, as a proxy of its openness to general MNEs' business operations, does not affect its capacity to specialize in our focal green technologies. As a first bit of evidence on the role of cognitive proximity between FDIs and green-techs (see RQ1), it thus appears that having a larger endowment of foreign subsidiaries/projects, operating in sectors with heterogeneous and possibly limited scope of environmental spillovers, does not help the region in mastering environmental technologies to the point of specializing in them.

Extremely relevant for our research question is the significant and positive sign that the pre-sample mean of the dependent variable reveals across each and every of our focal three green-technologies. Consistently with what the economic geography literature has extensively shown with respect to 'standard' technologies, all the green-tech specializations of our analysis appear strongly path-dependent, pointing to the crucial role of their cumulativeness for their development (Montresor and Quatraro, 2017). In the light of this result, as we argued in Section 2, it becomes interesting to investigate whether MNEs can help the region break up this path-dependence, or if they rather reinforce it: an issue to which we will dedicate in the following.

Table 3 - Baseline estimates

Dependent variable: RTA in selected technologies (dummy)	1 Environmental management	2 Climate change mitigation technologies related to energy generation, transmission or distribution	3 Climate change mitigation technologies related to transportation
Pre-sample mean (1979-2002)	1.659***	1.476***	2.243***
	(0.111)	(0.131)	(0.141)
Region's share of country patents	0.492	-0.622	-4.796
	(1.653)	(1.727)	(3.826)
Lagged RTA in KETs (dummy)	-0.0510	0.138***	-0.0221
	(0.0496)	(0.0491)	(0.0582)
log(GDP)	-0.0227	0.0720*	-0.0390
	(0.0378)	(0.0384)	(0.0468)
No inward FDI (dummy)	-0.0952	0.203*	-0.00113
	(0.123)	(0.123)	(0.136)
Number of inward FDI (log)	0.0132	-0.0362	-0.0350
	(0.0480)	(0.0468)	(0.0554)
FDI in env tech cluster (dummy)	0.0222	0.0705	0.0587
	(0.0774)	(0.0807)	(0.0882)
FDI in energy cluster (dummy)	0.0608	0.239**	0.00302
	(0.0974)	(0.0934)	(0.108)
FDI in transport cluster (dummy)	-0.0385	-0.00310	0.161*
	(0.0819)	(0.0791)	(0.0971)
FDI in other clusters (dummy)	-0.0315	0.0829	0.0856
	(0.122)	(0.123)	(0.134)
Pseudo R sq	0.136	0.101	0.216
N	3872	3875	3815

Probit model. Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: year dummies. Standard errors clustered by region in parenthesis.
* p<0.1, ** p<0.05, *** p<0.01.

With more specific reference to our first Research Question (RQ1), the argument that we have developed in Section 2 about the cognitive relationship between FDIs and environmental technologies appears confirmed to a certain extent. The proximity between the knowledge base of the two appears to be an important factor conditioning the technology affected by FDIs. Indeed, find evidence of significant correlations nearly exclusively for the proximate pairs of Table 1. FDIs in the transport cluster increases the chance of a regional specialisation only in climate change mitigation technologies related to transportation. In a similar vein, FDIs in the energy sector positively affect the regional capacity of gaining a revealed advantage only in climate change mitigation technologies related to energy.

Quite interestingly, the commonality of the domains between inward FDIs and regional environmental technologies appears crucial for the emergence of a relationship between the two, suggesting that, unlike for 'standard' technologies, the role of inter-domain (intersectoral like) FDI spillovers is negligible for environmental ones. The systematic non-significant effect non environmentally-sensitive FDIs, whose effects could only be, by construction, only 'intersectoral' and cognitive distant, support this conclusion. On the other hand, somehow unexpected is the lack of the effect of FDIs in the environmental technologies industries on the regional specialization in environmental management technologies. This result could be due to the fact that the FDIs in the former industries does not exclusively nor mainly refer to the management of already emerged environmental problems, as it is instead the case of the green technologies at stake, suggesting that there might be a lower cognitive proximity in this case as compared to the other pairs.[12] It is worth mentioning that these results are robust to various changes in the specification that we provide in the Appendix. In particular, in Table B1, we define a more onerous threshold for defining the technological specialization of a region at RTA>1.5. In Table B2, we add the lagged dependent variable to our specification. While this specification may introduce further econometric issues related to endogeneity of the lagged dependent variable, it is worth investigating whether our results are robust to this further control. In Table B3, we compute the pre-sample mean for a period farther away in time (1979-1994), to reduce concerns about endogeneity. Finally, in Table B4 we estimate a random effect model. Reassuringly, our main results are largely unchanged in all these robustness checks.

[12] Of course, this is a tentative explanation that would need a closer inspection of the relative domains to be confirmed.

Table 4 – Unpacking FDI by activity

Dependent variable: RTA in selected technologies (dummy)	1 Environmental management	2 Climate change mitigation technologies related to energy generation, transmission or distribution	3 Climate change mitigation technologies related to transportation
Pre-sample mean (1979-2002)	1.657***	1.474***	2.243***
	(0.111)	(0.131)	(0.142)
Region's share of country patents	0.396	-0.656	-5.027
	(1.635)	(1.733)	(3.937)
Lagged RTA in KETs (dummy)	-0.0509	0.137***	-0.0183
	(0.0496)	(0.0491)	(0.0581)
log(GDP)	-0.0229	0.0748*	-0.0455
	(0.0379)	(0.0386)	(0.0465)
No inward FDI (dummy)	-0.0897	0.198	0.00584
	(0.123)	(0.123)	(0.137)
Number of inward FDI (log)	0.00280	-0.0113	-0.0912
	(0.0521)	(0.0518)	(0.0588)
FDI in env tech cluster (dummy)	-0.312	0.186	0.254
- R&D investment	(0.216)	(0.212)	(0.212)
FDI in energy cluster (dummy)	0.278	-0.0586	0.468*
- R&D investment	(0.305)	(0.284)	(0.262)
FDI in transport cluster (dummy)	-0.0624	-0.171	0.361***
- R&D investment	(0.133)	(0.127)	(0.139)
FDI in other clusters (dummy)	0.0408	0.0138	0.254
- R&D investment	(0.156)	(0.156)	(0.171)
FDI in env tech cluster (dummy)	0.0486	0.0540	0.0681
- non-R&D investment	(0.0799)	(0.0831)	(0.0902)
FDI in energy cluster (dummy)	0.0443	0.253***	-0.0184
- non-R&D investment	(0.0982)	(0.0945)	(0.110)
FDI in transport cluster (dummy)	-0.0271	0.00316	0.165*
- non-R&D investment	(0.0834)	(0.0799)	(0.0998)
FDI in other clusters (dummy)	-0.0284	0.0671	0.111
- non-R&D investment	(0.123)	(0.123)	(0.135)
Pseudo R sq	0.137	0.102	0.218
N	3872	3875	3815

Probit model. Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: year dummies. Standard errors clustered by region in parenthesis.
* p<0.1, ** p<0.05, *** p<0.01.

As far as our second Research Question (RQ2) is concerned, Table 4 unpacks the effect of FDIs on the focal green-tech specialisations, by looking at the extent to which this effect is driven by FDIs in R&D. We find that, out of the two pairs of FDIs and green-technologies, the one based on transportation appears to pass mainly through FDIs in R&D (upper panel), while the FDIs in non-R&D activities within the same industries is only weakly significant (lower panel). Conversely, FDIs in R&D do not have a significant effect in the proximate pair based on energy. The effect of energy FDIs on the regional specialization in green energy technologies actually passes only through non-R&D activities, related to the manufacturing and commercialization phases of the value chain and to its other ancillary activities (e.g. ICT, maintenance, and the like).[13] In other words, FDIs do not appear to significantly affect energy technologies directly though the R&D activities of foreign affiliates, while other types of knowledge flows – not necessarily implying the set-up of a research lab by foreign MNEs - are likely to contribute to the green specialization of regions. Such knowledge flows might well occur by means of user-production relationships and demonstration effects. Exploring the reasons underlying these differences in R&D FDI effects across pairs of FDI and technologies is beyond the scope of this paper. Suffice here to mention that such distinctive patterns might have to do with differences in technological regimes, and with different roles and positions of regions in global value chains characterizing the two industry clusters. What is worth stressing here is that the green-tech specialization of regions does not necessarily pass through the attraction of R&D FDIs, and could benefit from non-R&D ones, depending on the sector in which FDIs occur.

Turning to our third Research Question (RQ3), Table 5 reports the estimates of equation (2) wherein the environmentally relevant FDIs are distinguished based on whether the region had (lower panel), or had not (upper panel), a prior specialisation in the relevant green technology.[14]. We find that, out of our two significant pairs, inward FDIs in the energy cluster are positively correlated with the proximate green specialization only in the case of regions that were not specialized in green energy technologies before: the role of FDIs in energy industries in favouring the regional shift from the non-green to the green realm appears thus confirmed. On the contrary, FDIs in transport correlates with the specialization in transportation related green technologies only for regions that were specialized in these technologies already. Hence FDIs in transport appear to help prevent the region from loosing the specialisation over time, but can hardly contribute the green transition of non-green regions.

[13] To be sure, although with a weak significance, R&D FDIs in the energy cluster do have an effect, but on the specialisation of a cognitive dissimilar green-technology, related to transportation.

[14] Results for control variables are not reported and remain available upon request.

Table 5 – Stability vs switch to green specialisation

Dependent variable: RTA in selected technologies (dummy)	1 Environmental management	2 Climate change mitigation technologies related to energy generation, transmission or distribution	3 Climate change mitigation technologies related to transportation
Pre-sample mean (1979-2002)	1.421***	1.294***	1.890***
	(0.110)	(0.129)	(0.139)
Region's share of country patents	0.909	-1.287	-3.819
	(1.518)	(1.689)	(3.619)
Lagged RTA in KETs (dummy)	-0.0506	0.125***	0.000844
	(0.0484)	(0.0481)	(0.0572)
log(GDP)	-0.0144	0.0721*	-0.0368
	(0.0365)	(0.0372)	(0.0450)
No inward FDI (dummy)	-0.0945	0.188	0.0325
	(0.122)	(0.122)	(0.134)
Number of inward FDI (log)	0.0208	-0.0339	-0.0363
	(0.0469)	(0.0455)	(0.0542)
FDI in env tech cluster (dummy)	-0.0264	0.0843	-0.0668
for 'not specialized' regions in t-1	(0.0993)	(0.0926)	(0.112)
FDI in energy cluster (dummy)	0.142	0.246**	0.0232
for 'not specialized' regions in t-1	(0.124)	(0.110)	(0.125)
FDI in transport cluster (dummy)	-0.0801	0.00794	0.139
for 'not specialized' regions in t-1	(0.0985)	(0.0892)	(0.112)
FDI in other clusters (dummy)	-0.296**	-0.136	-0.0989
for 'not specialized' regions in t-1	(0.129)	(0.127)	(0.136)
FDI in env tech cluster (dummy)	0.0290	0.0116	0.376**
for 'specialized' regions in t-1	(0.114)	(0.124)	(0.171)
FDI in energy cluster (dummy)	-0.0211	0.211	-0.105
for 'specialized' regions in t-1	(0.136)	(0.150)	(0.205)
FDI in transport cluster (dummy)	0.00730	-0.0248	0.297**
for 'specialized' regions in t-1	(0.105)	(0.113)	(0.144)
FDI in other clusters (dummy)	0.292**	0.479***	0.585***
for 'specialized' regions in t-1	(0.133)	(0.138)	(0.158)
Pseudo R sq	0.152	0.115	0.240
N	3872	3875	3815

Probit model. Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: year dummies. Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Our findings thus show that, while the dynamics of green innovation exhibits some substantial path dependence features, FDIs can play a key role in breaking up specialization patterns inherited from the past history of regions. On the one hand, in response to RQ1, we showed that multinational presence does affect EI in technological fields that are strongly related to the industry clusters in which FDIs occur. This is largely consistent with the emphasis of innovation geography literature on past and place dependence in the technological diversification of regions. On the other hand, addressing

RQ3, we highlighted that multinational presence does help breaking up lock-in effects over time, although with differences across industries. In fact, FDIs in energy clusters significantly contributes to the transition of regions from non-green to green specialization; while FDIs in transport industries do not significantly affect the green transition of regions that are not green, but contributes to the persistence of the specialization of regions that are green already.

5 Conclusions

The paper investigates the extent to which MNEs can help the regional specialization in green technologies. Given the increasing openness that regions are experimenting in the era of the global value chains (De Marchi et al., 2018), the role of MNEs in helping regions to develop eco-innovations is extremely important and in need of more in-depth investigation than the scanty and context-specific one it has received so far. On the one hand, systematic empirical evidence is needed to ascertain whether and to what extent a positive effect of inward FDIs on regional EI holds true in general, irrespectively from regional and MNE specificities. On the other hand, deeper conceptual analysis is required to understand the mechanisms through which the relationship between inward FDIs and regional green-tech eventually unfolds.

We address this analytical gap by combining environmental economics with innovation and international business studies and by proposing three research questions about i) the role of the cognitive proximity between FDIs and green-technologies in affecting the specialization of a region in certain environmental technologies, ii) the differential effect of R&D vs. non-R&D FDIs, and iii) the role of MNEs in breaking up the persistence of regional green-tech revealed advantages. Providing a first case of systematic empirical investigation of the issue, we then address these research questions with reference to a sample of 1,305 European NUTS3 regions over the period 2003-2014, combining the OECD-REGPAT and the Financial Times' fDi Markets dataset.

Our results show that inward FDIs help regions with their green-specialization, provided that they occur in cognitively close industries. In particular, regional specialization in energy and in transport related environmental technologies is associated with FDIs energy and transport related industries respectively. From a different, but equivalent perspective, this entails that the role of 'intersectoral' environmental spillovers of FDIs at the regional level is nearly negligible, and that MNEs can contribute to EI within the boundaries of the domains in which they invest.

Quite interestingly, in these two groups of industries FDIs appear to have different effects, both in terms of business activities they pass through and of their role in helping regions switch rather than keep their previous specialization pattern. First of all, the energy and transport industries differ in the extent to which foreign R&D activities are conducive to regional specialization in green technologies. On the one hand, the effect of FDIs in transport-related industries on transport-related technologies is driven by the MNEs' R&D activities in the region. On the other hand, FDIs in energy related industries contribute to the regional specialization in energy-related technologies through non-R&D activities. This is an extremely important result, which suggests that regional technological specialization could also benefit from FDI in business areas other than in R&D activities, such as input-output relations and informal (user-producer) learning spillovers.

An interesting difference between the two sectors also emerges in the role of MNEs in breaking the path-dependence of regional specialization, which thus appears more nuanced than previous studies on technological diversification have found. On the one hand, FDIs in energy-related industries appear capable to break path-dependent patterns, helping regions to switch from previous non-green to green-tech specialization. Conversely, FDIs in transport-related industries do not appear to significantly contribute to the switch but reinforce the persistence of green (related) specialization.

These results have important implications, in terms of both research and policy. As for the former, they suggest that MNEs can unlock the green door of regional development only by wearing suitable green-sensitive keys. On this basis, future research should concentrate on better characterizing the kind of "proximity" between MNEs and regional activities/firms, which is capable to favor the green regional transition. Furthermore, the mechanisms through which MNEs affect the regional specialization in green-tech is still largely a black-box. Future research should work on better identifying the direct contribution of MNEs to green innovation through the inventive activities of their subsidiaries and the indirect effects on the innovation of local firms. Some of our results in terms of differences across sectors and knowledge domain and of the role of R&D vs.

non-R&D FDI can form the basis for a more articulated theoretical and empirical development.

In terms of policy, the results that we have obtained suggest that favouring inward FDIs and supporting the insertion of local firms into global value chains could help the green transition under certain conditions: in particular, regions need to be capable to target the development of specific kinds of green technologies and to open up to foreign investments accruing to economic activities that are related to the such technologies.

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Appendix A – Additional information on data and descriptive evidence

Table A1 – Environmental technologies (source: OECD-ENVTECH)

Technology groups (OECD-ENVTECH)	Short name
1 Environmental management *1.1 Air pollution abatement* *1.2 Water pollution abatement* *1.3 Waste management* *1.4 Soil remediation* *1.5 Environmental monitoring* 2 Water-related adaptation technologies *2.1 Demand-side technologies (water conservation)* *2.2 Supply-side technologies (water availability)* 5 Capture, storage, sequestration or disposal of greenhouse gases *5.1 CO2 capture or storage (CCS)* *5.2 Capture or disposal of greenhouse gases other than carbon dioxide (N2O, CH4, PFC, HFC, SF6)* 8 Climate change mitigation technologies related to wastewater treatment or waste management *8.1 Wastewater treatment* *8.2 Solid waste management* *8.3 Enabling technologies or technologies with a potential or indirect contribution to greenhouse gas emission mitigation*	Environmental management
4 Climate change mitigation technologies related to energy generation, transmission or distribution *4.1 Renewable energy generation* *4.2 Energy generation from fuels of non-fossil origin* *4.3 Combustion technologies with mitigation potential (e.g. using fossil fuels, biomass, waste, etc.)* *4.4 Nuclear energy* *4.5 Efficiency in electrical power generation, transmission or distribution* *4.6 Enabling technologies in energy sector* *4.7 Other energy conversion or management systems reducing GHG emissions*	Climate change mitigation technologies related to energy generation, transmission or distribution
6 Climate change mitigation technologies related to transportation *6.1 Road transport* *6.2 Rail transport* *6.3 Air transport* *6.4 Maritime or waterways transport* *6.5 Enabling technologies in transport*	Climate change mitigation technologies related to transportation
7 Climate change mitigation technologies related to buildings *7.1 Integration of renewable energy sources in buildings* *7.2 Energy efficiency in buildings* *7.3 Architectural or construction elements improving the thermal performance of buildings* *7.4 Enabling technologies in buildings*	Climate change mitigation technologies related to buildings
9 Climate change mitigation technologies in the production or processing of goods *9.1 Technologies related to metal processing* *9.2 Technologies relating to chemical industry* *9.3 Technologies relating to oil refining and petrochemical industry* *9.4 Technologies relating to the processing of minerals* *9.5 Technologies relating to agriculture, livestock or agroalimentary industries* *9.6 Technologies in the production process for final industrial or consumer products* *9.7 Climate change mitigation technologies for sector-wide applications* *9.8 Enabling technologies with a potential contribution to greenhouse gas emissions mitigation*	Climate change mitigation technologies in the production or processing of goods

Figure A1 – Trend in the share of EPO patent applications in EU regions, by class of environmental technology, 1979-2014 (4-year time windows)

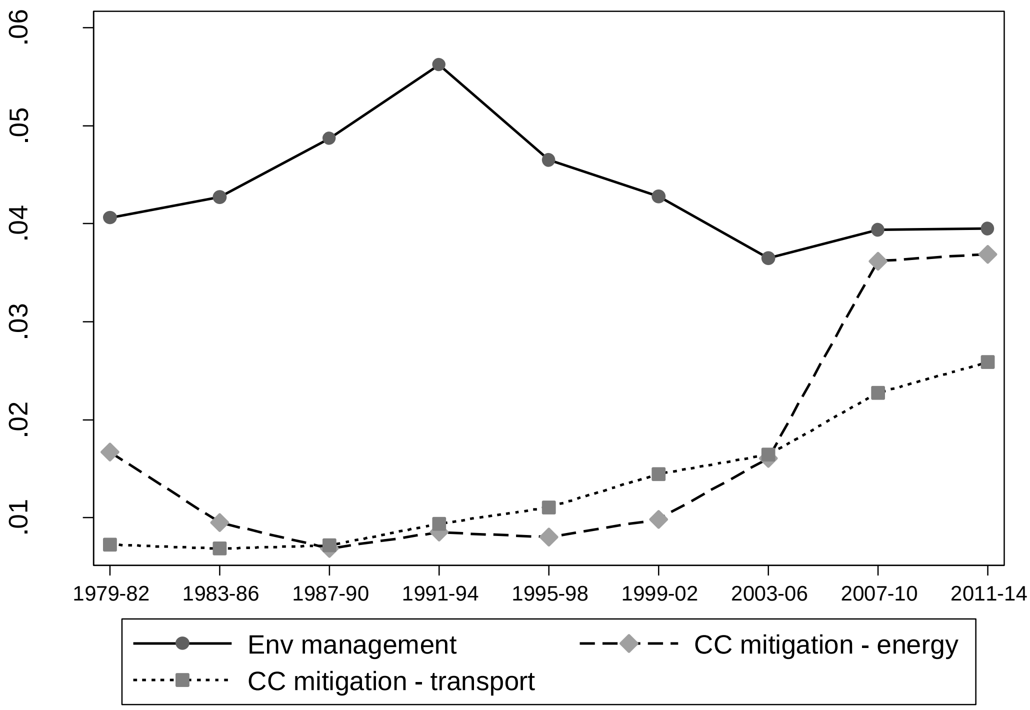
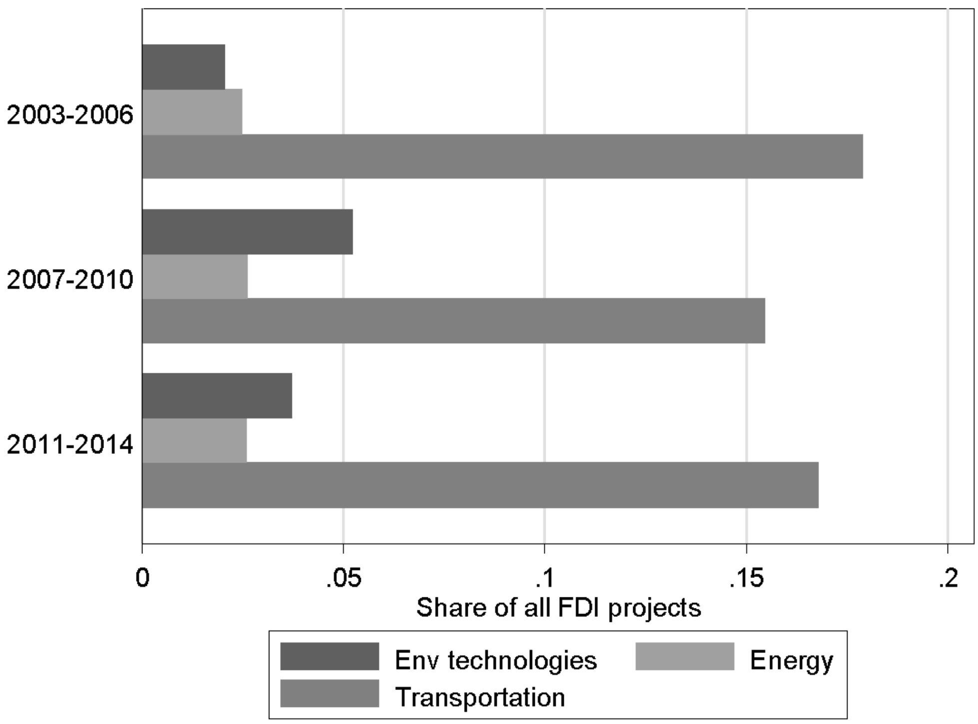


Figure A2 – Composition of FDI projects by environmental related cluster



Appendix B – Robustness checks

Table B1 – Specialization defined with RTA>1.5

Dependent variable: RTA in selected technologies (dummy)	1 Environmental management	2 Climate change mitigation technologies related to energy generation, transmission or distribution	3 Climate change mitigation technologies related to transportation
Pre-sample mean (1979-2002)	1.870***	1.652***	2.303***
	(0.123)	(0.157)	(0.163)
Region's share of country patents	-3.037	-0.625	-5.884*
	(2.693)	(1.784)	(3.559)
Lagged RTA in KETs (dummy)	-0.124	0.0645	-0.0346
	(0.0788)	(0.0763)	(0.0927)
log(GDP)	-0.0847**	-0.0274	-0.0963**
	(0.0380)	(0.0376)	(0.0489)
No inward FDI (dummy)	-0.0998	0.0670	0.0324
	(0.130)	(0.131)	(0.149)
Number of inward FDI (log)	-0.00730	0.00420	-0.0134
	(0.0474)	(0.0475)	(0.0583)
FDI in env tech cluster (dummy)	0.0749	0.0585	-0.0115
	(0.0850)	(0.0874)	(0.103)
FDI in energy cluster (dummy)	0.0658	0.268***	0.0189
	(0.0985)	(0.0960)	(0.124)
FDI in transport cluster (dummy)	0.00217	-0.0757	0.206**
	(0.0820)	(0.0866)	(0.104)
FDI in other clusters (dummy)	0.0192	-0.0517	0.0500
	(0.130)	(0.127)	(0.142)
Pseudo R sq	0.124	0.0788	0.180
N	3875	3839	3759

Probit model. Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: year dummies. Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Table B2 – Results adding lagged dependent variable

Dependent variable: RTA in selected technologies (dummy)	1 Environmental management	2 Climate change mitigation technologies related to energy generation, transmission or distribution	3 Climate change mitigation technologies related to transportation
Pre-sample mean (1979-2002)	1.205***	1.066***	1.614***
	(0.105)	(0.122)	(0.132)
Lagged dependent variable	0.663***	0.588***	0.796***
	(0.0517)	(0.0539)	(0.0638)
Region's share of country patents	0.827	-1.055	-4.521
	(1.430)	(1.597)	(3.530)
Lagged RTA in KETs (dummy)	-0.0419	0.112**	-0.00594
	(0.0474)	(0.0471)	(0.0566)
log(GDP)	0.00388	0.0670**	-0.0136
	(0.0335)	(0.0341)	(0.0419)
No inward FDI (dummy)	-0.0719	0.238*	-0.00516
	(0.124)	(0.125)	(0.137)
Number of inward FDI (log)	0.0159	-0.0306	-0.0309
	(0.0452)	(0.0440)	(0.0528)
FDI in env tech cluster (dummy)	0.00283	0.0597	0.0266
	(0.0785)	(0.0802)	(0.0894)
FDI in energy cluster (dummy)	0.0814	0.226**	-0.000184
	(0.0957)	(0.0917)	(0.110)
FDI in transport cluster (dummy)	-0.0458	0.00530	0.164*
	(0.0817)	(0.0776)	(0.0966)
FDI in other clusters (dummy)	-0.0361	0.128	0.0695
	(0.125)	(0.125)	(0.134)
Pseudo R sq	0.171	0.129	0.256
N	3872	3875	3815

Probit model. Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: year dummies. Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Table B3 – Pre-sample mean based on information for 1979-1994

Dependent variable: RTA in selected technologies (dummy)	1 Environmental management	2 Climate change mitigation technologies related to energy generation, transmission or distribution	3 Climate change mitigation technologies related to transportation
Pre-sample mean (1979-1994)	0.983***	0.830***	1.597***
	(0.101)	(0.124)	(0.133)
Region's share of country patents	0.794	0.129	-4.571
	(1.773)	(1.772)	(3.839)
Lagged RTA in KETs (dummy)	-0.0308	0.157***	-0.0640
	(0.0498)	(0.0491)	(0.0582)
log(GDP)	-0.0113	0.105***	-0.0385
	(0.0394)	(0.0389)	(0.0478)
No inward FDI (dummy)	-0.0874	0.211*	-0.0119
	(0.121)	(0.122)	(0.137)
Number of inward FDI (log)	0.00242	-0.0461	-0.0336
	(0.0474)	(0.0474)	(0.0567)
FDI in env tech cluster (dummy)	0.0362	0.0958	0.0154
	(0.0759)	(0.0796)	(0.0877)
FDI in energy cluster (dummy)	0.0855	0.249***	-0.0160
	(0.0956)	(0.0919)	(0.107)
FDI in transport cluster (dummy)	-0.00243	-0.00137	0.189**
	(0.0803)	(0.0788)	(0.0960)
FDI in other clusters (dummy)	0.00276	0.0986	0.0762
	(0.120)	(0.121)	(0.135)
Pseudo R sq	0.0978	0.0796	0.176
N	3872	3875	3815

Probit model. Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: year dummies. Standard errors clustered by region in parenthesis.
* p<0.1, ** p<0.05, *** p<0.01.

Table B4 – Random effects probit model

Dependent variable: RTA in selected technologies (dummy)	1 Environmental management	2 Climate change mitigation technologies related to energy generation, transmission or distribution	3 Climate change mitigation technologies related to transportation
Pre-sample mean (1979-2002)	2.071***	1.850***	2.910***
	(0.142)	(0.170)	(0.203)
Region's share of country patents	0.818	-1.084	-5.280
	(1.980)	(2.179)	(4.918)
Lagged RTA in KETs (dummy)	-0.0626	0.134**	-0.00358
	(0.0592)	(0.0586)	(0.0729)
log(GDP)	-0.0122	0.0986**	-0.0325
	(0.0473)	(0.0486)	(0.0604)
No inward FDI (dummy)	-0.101	0.316**	-0.0184
	(0.145)	(0.152)	(0.170)
Number of inward FDI (log)	0.0177	-0.0449	-0.0794
	(0.0568)	(0.0561)	(0.0704)
FDI in env tech cluster (dummy)	0.0637	0.0526	0.0920
	(0.0936)	(0.0965)	(0.111)
FDI in energy cluster (dummy)	0.0796	0.261**	0.00577
	(0.116)	(0.110)	(0.136)
FDI in transport cluster (dummy)	-0.0663	0.0106	0.201*
	(0.0967)	(0.0932)	(0.120)
FDI in other clusters (dummy)	-0.0593	0.174	0.101
	(0.145)	(0.151)	(0.164)
N	3872	3875	3815

Random effects probit model. Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: year dummies. Robust standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.