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Abstract

This paper builds on (eco-)innovation geography and international business studies to investigate the effects of greenfield foreign direct investments (FDIs) on regional specialisation in environmental technologies. Combining the OECD-REGPAT and the fDi Markets datasets with respect to 1,050 European NUTS3 regions over the 2003–2014 period, we find that FDIs can positively impact regions' specialisation in green technologies. This effect is statically significant when FDIs occur in industries where environmental patents represent a relatively high share of total inventive activities (green-tech FDIs), and it is further reinforced if such foreign investments involve R&D activities. We also find that green-tech R&D FDIs have a larger effect in regions whose prior knowledge base is highly unrelated to environmental technologies. Furthermore, green-tech FDIs in R&D contribute to maintaining the specialisation of regions in environmental technologies over time, while it is only for high levels of unrelatedness that such FDIs help regions acquire a green-tech specialisation ex novo.

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1 Introduction

Environmental sustainability is an inescapable priority nowadays, giving rise to increasing interest in the development of 'green technologies' capable of reducing pollution and economising the use of natural resources. While early studies paid little attention to the geography of such technologies (Truffer and Coenen, 2012), recent research has emphasised that environmental innovations (EIs) have an important regional dimension: spatial and relational proximities, urbanisation and agglomeration economies, local networks and institutional setups contribute to making EIs unevenly distributed in space (Cooke, 2011, 2012; Horbach 2014; Barbieri et al., 2016; Gibbs and O'Neill, 2017; Leoncini et al., 2016; Consoli et al., 2019; Montresor and Quatraro, 2019; Santoalha and Boschma, 2021).

Regions are differently equipped to eco-innovate for a number of reasons. Among the drivers of the regional capacity to eco-innovate and eventually specialize in green technologies, inward foreign direct investments (FDIs) and the activities of multinational enterprises (MNEs) have received surprisingly little attention so far.[1] This lack of empirical research limits our understanding of the patterns through which FDIs may affect the capacity of regions to develop and/or employ new technologies to transition towards the green-economy (Truffer and Coenen, 2012). Understanding whether FDIs help regions develop eco-innovation is relevant from both a conceptual and policy perspective. As we will argue more extensively in Section 2, the analysis of the role of FDIs in shaping the geography of green technologies is an important step towards a more comprehensive theoretical approach to regional EIs that, while recognising the fundamental role of local knowledge recombination, also considers exposure to external knowledge sources. From a policy perspective, the same kind of analysis can be useful in showing how the attraction of FDIs (of a suitable kind) can complement the toolbox of smart specialisation policies, based on related technological diversification, in such a way as to enable regions to green their technological base.

[1] The evidence on the impact of MNEs on local EIs is mainly based on case studies and national surveys, the insights of which are useful but not always generalisable (Cainelli et al., 2012; Chiarvesio et al., 2015). Some evidence of global patterns in the regional development of green technologies and of environmental upgrading has been recently obtained in the literature on global value chains (see De Marchi and Gereffi, 2018; De Marchi et al., 2020).

Our study addresses a number of questions concerning the effects of FDIs on the green-tech specialisation of regions, the answers to which help foster a better understanding of this relation and can inform policymaking aimed at steering the local development of green technologies. We follow two strictly interconnected lines of inquiry, along which we develop four research hypotheses.

As for the first line of inquiry, we investigate how the *nature* of FDIs affects regional specialisation in environmental technologies. On the one hand, we develop theoretical arguments suggesting that FDIs in industries that are more prone to introducing green innovations are more conducive to green technological specialisation (Hypothesis 1). On the other hand, within these industries we submit that it is R&D-intensive FDIs that provide the greatest contribution to regional EIs (Hypothesis 2).

Our second line of inquiry consists in analysing whether FDIs can act as 'agents of structural change' in the green technological domain. Accordingly, we claim that FDIs can be expected to enable regions to undertake a more explorative process of recombining existing knowledge, which can lead them to specialise in green technologies relatively less related to their previous specialisations (Hypothesis 3). Moreover, we investigate whether the green-tech-enabling role of FDIs is greater in regions that are already specialised and aim to maintain their green-tech status over time or, rather, in regions that were not previously specialised (Hypotheses 4a and 4b).

By combining the OECD-REGPAT and the fDi Markets datasets, with reference to 1,050 European NUTS3 regions over the 2003–2014 period, we show that the nature of FDIs does matter for explaining the green-tech specialisation of regions. In fact:

i) A positive and significant correlation is found when FDIs occur in industries that have a 'green technological footprint'—that is, industries in which environmental patents represent a relatively high share of total inventive activities. We identify these FDIs as 'green-tech FDIs';

ii) The effect of these green-tech FDIs is further reinforced if they involve R&D activities, which possibly increase the local knowledge base directly and spur the emergence of green inventions.

The structural change effects are also broadly confirmed, with some important nuances:

(iii) Green-tech FDIs in R&D activities are found to facilitate regional specialisation in green technologies more unrelated to previous specialisations.[2] For example, with the injection of foreign R&D knowledge in 'waste management and remediation services' (specialised in green patents across the world, as reported in Appendix 1), a region with pre-existing specialisations in transport technologies could specialise in technologies for climate change mitigation related to waste management even if, in the absence of these FDIs, its pre-existing transport knowledge base would have only allowed it to access a more cognitively related green technology, such as that aimed at mitigating climate change effects related to transportation. More generally, FDIs act as agents of structural change that help regions diversify in green technological fields more distant (unrelated) to their current capabilities. In this way, they can contribute to breaking lock-ins and place dependence in regional technological specialisation.

iv) Our findings also reveal that FDIs facilitate the persistence of specialisation in environmental technologies in the case of regions that already exhibit such a specialisation, whereas they generally do not help ex-novo acquisition. For example, it may well be that inward R&D FDIs in an industry like 'wind electric power' (a green-tech industries listed in Appendix 1) over time help the recipient region extend the range of technologies for air pollution abatement in which it was already active (including technologies that are unrelated to the regional knowledge base, consistent with the findings illustrated in point (iii) above). However, such an injection of foreign R&D would not be enough to allow the region to master ex-novo air pollution abatement technologies if it had no pre-existing experience in this domain. In other words, while contributing to breaking place dependence in regional technological specialisation, FDIs do not manage to break its strictly path-dependent development.

Our results bear implications for how we conceptualise regional EIs, as well as for industrial policy aimed at facilitating the development of green technologies. From a theoretical point of view, we empirically support an 'augmented' approach to the

[2] As we further explain in the following section, the idea of technological relatedness has been introduced in the geography of innovation literature to indicate the average cognitive proximity that links the technology in which a region enters by specialising and those in which it was already specialised and that were already part of its knowledge base (see Balland, 2016). The cognitive proximity between technological pairs is in turn conceptualised by looking at the extent to which they rely on similar capabilities, as reflected by their co-occurrence in the inventing process.

geography of environmental technologies, in which their development through local knowledge recombination integrates the driving and mediating role of external knowledge sources like FDIs. From a policy point of view, we suggest that strategies for the 'smart' development of local green technologies could benefit from a policy mix including inward FDI promotion and selection, provided that their industry and functional nature are closely scrutinised.

The rest of the paper is structured as follows. Section 2 positions the paper in the different streams of literature it relates to and puts forward our research hypotheses. Section 3 illustrates the empirical application, and Section 4 discusses the results. Section 5 offers some concluding remarks.

2 Background literature and research hypotheses

As mentioned in the previous section, the lack of studies on the role of FDIs in shaping the geography of green technologies represents an important gap in the literature about regional EIs, the filling of which is relevant in both conceptual and policy terms.

From a conceptual point of view, it is important to understand whether inward FDIs can constitute a channel through which external knowledge enriches host regions and augments opportunities for local knowledge recombination, which the geography of environmental technologies has been argued to depend on (Montresor and Quatraro, 2019). Regions have been found to specialise in green technologies that are cognitively close (i.e. 'technologically related') to pre-existing local ones, and this has been interpreted as confirmation of the occurrence of regional EIs of a recombinant nature (Van den Berge and Weterings, 2014). However, regions are not 'territorial containers' of knowledge, assets, and conventions, as an inward-looking conception of regional worlds tends to maintain (Yeung, 2021). Instead, regional boundaries are highly porous and external knowledge constantly penetrates them along a variety of channels through it interacts with local knowledge in different ways and the eco-innovative outcomes of which are worth investigating. Given their recognised properties in shaping the knowledge and assets of the recipient locations, FDIs are certainly one of the most relevant of these channels.

Filling the gap in our knowledge of the role of inward FDIs for regional green technologies is also important in terms of policy. Recent policy documents in the area of smart specialisation strategies (S3) have claimed that regional policymakers should 'smartly' spur local stakeholders to utilise and recombine their existing knowledge bases in order to 'green' their technologies and economies (EC, 2012). However, this indigenous local recombination might be too binding for EIs to occur (Montresor and Quatraro, 2019). Attracting FDIs of a suitable kind could thus become the spanning leverage through which regional policymakers can increase the green contamination of the local knowledge base and the scope of knowledge recombination opportunities through which EIs occur.

As anticipated in the previous section, our study addresses a number of questions related to the effects of FDIs on the technological specialisation of regions in environmental technologies. Our investigation moves in two directions, along each of which we put forward two research hypotheses in the following subsections. In Section 2.1, we argue that a) the green-tech nature of FDIs, as revealed by the eco-inventive specialisation of the industries in which they occur, is key to explaining regional specialisation in environmental technologies, and b) R&D-intensive FDIs provide a greater contribution to regional EI. In Section 2.2, we analyse the role of FDIs in enabling structural change in the environmental technological specialisation of regions, and we posit that green-tech FDIs in R&D activities can be expected to facilitate regional specialisation in green technologies that are more unrelated to previous specialisations; while we have competing hypotheses on whether they help specialisation in environmental technologies in regions that are already specialised in the green-tech domain or, rather, foster the acquisition of a green-tech specialisation ex novo.

2.1 The nature of inward FDIs and their effects on regional green-technology specialisation

The effect of inward FDIs on local EIs is difficult to predict. Empirical research largely reflects this indeterminacy, although most extant evidence has mainly addressed the impact of FDIs on environmental performance (e.g., emissions) rather than their effects on EIs as such (for recent surveys, see Cole et al., 2017; Zugravu-Soilita, 2017). This indeterminacy largely depends on the fact that FDIs are heterogeneous and not all FDIs are conducive to green innovation in the receiving regions. Two key dimensions of the heterogeneity of FDI are a) the extent to which the industries in which FDIs occur are conducive to green innovation, and b) the R&D and innovation contents of FDIs.

First, the role of FDIs in contributing to regional EIs is apparently less indeterminate when a focus is placed on what some recent literature has called *'green FDIs'*. Unfortunately, no single widely adopted definition of 'green FDI' has been agreed upon in the literature. A recent report by Greeninvest (2017) provides a useful survey of various attempts to define the concept. Despite their differences, all definitions seem to point to environmentally relevant sectors. Building on this literature and considering that our analysis is specifically targeted at explaining innovation in green technologies, we define 'green-tech FDIs' as cross-border investments occurring in narrowly defined industries where environmental technological innovations are most relevant. We refer the reader to Section 3.2.2 for details on how we operationalise this definition. However, let us simply note here that in order to identify green-tech FDIs, we first characterise industries based on their relative propensity to patent in green technological domains, as identified by established classifications of green patent classes, and we then associate FDIs with these industries. In brief, green-tech FDIs occur in industries whose knowledge base is characterised by a relatively higher share of green patents (i.e. inventive knowledge) across the world or, technically speaking, which have a revealed technological advantage (RTA) in green technologies. The list of industries used to identify green-tech FDIs is presented in Appendix B. It is worth noting that according to our definition, industries with a green RTA (i.e. with a value of the indicator larger than 1) do not need to be environmentally friendly but, rather, need to reveal opportunities of eco-innovating that are relatively greater than their total innovative opportunities. In this sense, an industry like iron ore mining, whose environmental impact (e.g. in terms of emissions) is arguably quite high, is one in which the inventive efforts to reduce this impact and to eco-innovate are comparatively greater than its inventive efforts in other technological domains. Accordingly, FDIs that occur in these industries can be claimed to contribute to their green knowledge base and to concur to the international spread of the eco-innovative efforts of the same industries. In the same respect, it should be noted that the complement to our green-tech FDIs is not necessarily 'brown-tech FDIs' but, rather, FDIs in industries whose green inventive efforts are comparatively lower than their total inventive efforts.

We submit that FDIs occurring in these industries are more likely to induce environmental innovation. Hence, regions that receive more FDIs in these industries—henceforth identified as regions attracting 'green-tech FDIs'—can be expected to be better positioned in the development of green technologies. In contrast, non-green-tech FDIs—that is, FDIs accruing to industries that are not specialised in green technologies—are arguably more effective in pushing regions towards alternative (non-green) specialisations (Sawhney and Rastogi, 2015). It is crucial to highlight that the simple observation that green-tech FDIs are associated with regional specialisation in environmental technologies does not suggest a causal relation. Indeed, it is quite likely that green-tech FDIs flow more to regions that are already specialised in green technologies. We carefully account for this unobserved heterogeneity issue in our empirical analysis.

Green-tech FDIs can increase regional eco-innovativeness in a direct and an indirect way. On the one hand, subsidiaries of foreign MNEs investing in the region can *directly* steer the technological specialisation of the region towards green technologies, to the extent that MNEs are actually more involved in green innovation than local firms (Kaway et al., 2018). On the other hand, FDI could have *indirect* effects by affecting green innovation in the wider local economy, through knowledge spillovers on domestic (regional) firms (Ning and Wang, 2018). For example, in order to eco-innovate foreign subsidiaries might require local suppliers to provide them with environmentally sensitive inputs, the supply of which may require these suppliers to eco-innovate in turn, thus representing a positive externality. On the other hand, it could be that more eco-innovative foreign subsidiaries make the environmental outcomes of local firms less viable on the market and less attractive to local customers, thus representing a case of negative externality.

The literature has found wide support for the direct effect of FDI on innovative activity as a whole (Cantwell, 1989; Castellani and Zanfei, 2006; Guadalupe et al., 2012; Stiebale, 2016), and some evidence has also been found for indirect effects (Castellani et al., 2015; Crescenzi et al., 2015, Papanastassiou et al., 2020). However, the evidence regarding these two potential effects on green innovation is scanty, sparse, and mixed. The direct effect of FDIs on greening local innovation has been found to reflect several characteristics of both home and host countries (Carraro and Topa, 1994; Beise and Rennings, 2005; Haščič I. and Migotto, 2015; Tatoglu et al. 2014; Noailly and Ryfisch, 2015; Costantini et al. 2017; Kawai et al. 2018; Marin and Zanfei, 2019). Some studies have also shown that foreign firms' inventive activities in green domains can contribute—indirectly—to increasing the sustainability of domestic firms (Albornoz et al., 2009; Dechezleprêtre and Glachant, 2014), but this depends on a wide set of circumstances (Cainelli et al., 2012; Rezza, 2013; Tang, 2015), which cannot be easily reconciled with a straightforward interpretation.

Due to data limitations, disentangling direct and indirect effects empirically is beyond the scope of this paper.[3] However, one could venture saying that when MNEs carry out R&D in the host regions, while their activities are conducive to both direct and indirect effects on regional EI, the former effects are particularly likely.

This leads to the second key dimension of heterogeneity in the nature of FDIs, which refers to the *functional activities* involved in FDIs. In fact, MNEs' strategic decisions to invest in specific business activities—such as R&D, manufacturing, and sales, or combinations thereof—is likely to influence the technological specialisation of the regions in which FDIs are located. This is particularly the case of international investment decisions in the fields of research and development (R&D) and of innovation activities, that is, FDIs through which MNEs pursue a 'knowledge-intensive' strategy (Papanastassiou et al., 2020). Indeed, also with respect to environmental technologies R&D FDIs are likely to provide both a greater direct contribution to local innovation (Griffith et al., 2006; Dachs and Peters, 2014) and a potential for significant spillover to the innovation of local firms (Braconier et al., 2001; Castellani and Zanfei, 2006; Todo, 2006; Fu, 2008; Marin and Sasidharan, 2010; Belitz and Mölders 2016). For example, the regional specialisation in fuel cell technology—one leading green tech of this era—is unsurprisingly helped by R&D FDIs in local automotive industries. Given the increasing reliance of these industries on fuel cells, foreign R&D investment in this technology could increase the knowledge base of the region towards the acquisition of the relevant specialisation (Tanner, 2016).

Based on the discussion above, we put forward the following hypotheses:

[3] In particular, one would need to assign regional patent data to MNEs in each region. But in identifying MNEs, consolidating ownership structures of subsidiaries is only possible with a narrow geographical focus. As we will illustrate, our analysis exploits data across all NUTS3 regions in the EU over the 2003–2014 period. However, distinguishing the direct and indirect effects that FDIs can have on regional green-tech specialisation is key to understanding the role of FDI in regional eco-innovation and is in our research agenda.

Hypothesis 1: *The effect of inward FDIs on the regional capacity to specialise in environmental technologies is higher for green-tech FDIs, i.e. for foreign investments occurring in industries specialised in green inventions.*

Hypothesis 2: *The effect of green-tech FDIs on the regional capacity to specialise in environmental technologies is higher when FDIs are in R&D activities*.

By combining Hypotheses 1 and 2, we expect that the largest effect on regional green-tech specialisation is played by green-tech FDIs in R&D.

2.2 Inward FDIs and structural change in green-tech regional specialisation

While Section 2.1 explored the effect of inward FDIs on regional specialisation in environmental technologies, it did not delve into the dynamics of such technological specialisation. The starting point of this discussion is the understanding that innovation tends to follow cumulative and path-dependent trajectories (Dosi, 1982, 1988; Silverberg et al., 1988; Arthur 1989). Along these trajectories, the patterns of technological specialisation of firms, sectors, and countries change very slowly over time and are generally persistent. A similar phenomenon has also been detected in the context of the geography of innovation and has been qualified as 'place-dependence', or 'related diversification' (Boschma, 2017). This is a process that leads regions to change their technological specialisation over time by remaining close, in cognitive terms, to their pre-existing technologies—that is, by developing technologies that draw on capabilities that are similar to those on which pre-existing ones rely. In a nutshell and scaling up what happens at the company level, this occurs because regions also find it easier and less risky to enter new technologies by recombining existing knowledge and gradually change their technological repertoire into fields that are related to their previous specialisations (Boschma and Frenken, 2006; Neffke et al., 2011; Montresor and Quatraro, 2019).

If we view technological diversification or the emergence of new local technologies substituting previous ones as forms of regional structural change (Boschma, 2021), related diversification can be considered a 'weak' kind of structural change, as opposed to a 'strong structural change that instead characterises unrelated diversification. Indeed, while regions normally change their technological structure according to the former, there exist factors that, by attenuating the role of relatedness (that is, the fact that technologies develop more easily in a related way) make them capable of increasing the strength of change towards the latter type (Montresor and Quatraro, 2017). This has also been found with respect to green technologies. Recent studies have in fact shown that regional diversification into green technologies benefits from relatedness to pre-existing technological specialisations (Tanner, 2014; Van den Berge and Weterings, 2014; Montresor and Quatraro, 2019; Santoalha and Boschma, 2021). However, in the same studies there is also evidence that some regional factors attenuate the effect of relatedness on diversification (in econometric terms, they negatively moderate this effect) by giving regions scope for more technologically unrelated green-tech diversification, i.e. for a stronger kind of structural change. For example, Montresor and Quatraro (2019) and Antonietti and Montresor (2021) highlight the negative moderating role of Key Enabling Technologies (KETs), while Santoalha and Boschma (2021) focus on that of political support for environmental policy. Both KETs and institutional factors can thus be thought of as drivers of green-tech diversification that induce regions to specialise in technologies that are less related to their pre-existing ones and that, in doing so, act as factors of (strong) structural change.

We propose here that FDIs can be among the factors enhancing strong structural change. In particular, by injecting the host region with nonlocal knowledge and capabilities, FDIs can help the development of green technologies in regions that were previously specialised in technologies less related to them. Indeed, the role of MNEs and FDIs as actors of structural change has long been emphasised in the literature. MNEs tend to concentrate in sectors with a relatively high knowledge intensity, are characterised by high firm-level (vs plant-level) fixed costs, and are relatively larger in size than domestic firms (Barba Navaretti and Venables, 2006; Antràs and Yeaple, 2014). This implies that inward FDIs tend to change the structure of the economy, moving resources towards sectors where MNEs are active. In addition, despite some changes in the last decades MNEs typically invest abroad to exploit their superior technologies and firm-specific advantages, thus relying less than other firms on local capabilities (Buckley and Casson, 1976; Dunning, 1980; Narula et al., 2019). The contribution of MNEs and FDIs to structural change has been widely documented in developing (Mühlen and Escobar, 2019; Pineli et al., 2021) and transition countries (Kalotay, 2010), but evidence on developed countries is also available. For example, the specialisation of the UK and Spain in the automotive industry is fundamentally driven by the presence of foreign MNEs (Picknernell, 1998; Aláez-Aller et al., 2015).

The role of MNEs and FDI as agents of structural change at the regional level has attracted less research. Based on an empirical study of UK local labour market areas, Ascani and Iammarino (2018) suggest that foreign MNEs in manufacturing can act as catalysts for regional structural change by stimulating employment in intermediate services via demand linkages. Neffke et al. (2018) provide a systematic investigation of the link between firm dynamics and structural change at the regional level by using a diversification perspective. They argue (and test with reference to Sweden) that new plants of nonlocal agents (e.g. originating from outside the region) introduce more unrelated diversification than local start-ups and incumbents because they rely less on capabilities in the host region and more on those from other regions (including their home regions). In this perspective, these firms become a conduit of capability diffusion. Elekes et al. (2019) build on Neffke et al. (2018) to argue that foreign-owned firms are exemplary actors in such capability diffusion. They show that in Hungary, the capabilities of foreign firm are quite different from the region's average and, thus, induce significant structural change in regions, still in terms of unrelated diversification. In other words, since inward FDI can be a vehicle for transplanting a bundle of resources and capabilities into a region (Barba Navaretti and Venables, 2006 Boschma et al., 2017), it can be expected to be more valuable (in terms of the probability of developing environmental technologies) for regions that were previously specialised in technologies less related to environmental technologies.

We argue that similar structural-change mechanisms are at work also with respect to environmental technologies. More precisely, following from Hypothesis 1 and 2 we expect that the structural-change effect of FDIs on green-tech specialisation is stronger in the case of green-tech FDI in R&D. This leads us to formulate the following hypothesis:

Hypothesis 3*: The effect of green-tech FDIs (in R&D activities) on the regional capacity to specialise in environmental technologies is higher when pre-existing technologies are more unrelated to these.*

This hypothesis considers the technologies in which the regions that come to specialise in environmental technologies were already specialised: in brief, the technologies characterising their knowledge base. The regional knowledge base could already include green technologies in the basket of its constitutive technologies: in this case, FDIs could help regions maintain their relative specialisation over time and remain green in technological terms. Conversely, we could have regions that come to specialise in environmental technologies ex novo, their knowledge base being constituted by pre-existing non-green technologies only. In this case, FDIs can help regions implement changes in the socio-technical system that are part of the so-called ‘green-transition’ (Geels, 2002). There seems to be no conclusive evidence on whether the effect is greater in terms of helping regions acquire a green-tech specialisation or in terms of helping them maintain a green-tech specialisation over time. A recent stream of research on regional green industrial path development confirms the heterogeneity of the role played by foreign actors in initiating such a path (Trippl et al., 2020). Case-based evidence has actually shown that foreign actors like MNEs are crucial for ‘path importation’, in which green industries (and technologies) are actually new to the region and are transplanted into it through non-local actors: the cases of the offshore wind industry in Northeast England (Dawley, 2014) and of the on-site water recycling sector in China (Binz et al., 2016) are two typical examples in the literature. Conversely, FDIs are less pivotal in the case of ‘path diversification’, in which green industries (and technologies) are already present in the region and their knowledge and assets are transferred to other green ones. The development of the offshore wind industry in Norway, in a region previously specialised in the onshore wind sector represents an example of this (Steen and Hansen, 2018). When looking at this partially contradictory evidence based on case studies, it appears quite clear that the move to green specialisation is not an easy ride. Local firms, industrial systems, and institutions exposed to new technological opportunities in green domains tend to exhibit some rigidities and a lack of capacity to absorb and recombine the new knowledge transferred via FDIs. This rigidity and resistance to change might hinder the acquisition of a green-tech specialisation ex novo, i.e. when no experience of its use pre-exists in the region. In other words, while FDIs do inject external knowledge that might help reinforce existing green-tech specialisations (even in technological domains that are largely unrelated to the regional knowledge base, as our discussion of Hypothesis 3 suggests), the entry into a new green-tech specialisation with no roots in the local industrial system might encounter higher barriers and costs. To better explore this line of research and overcome the lack of systematic quantitative analyses that has so far characterised it, we put forward the following competing hypotheses:

Hypothesis 4a*: The effect of green-tech FDIs (in R&D activities) on the regional capacity to specialise in environmental technologies is greater in regions that are not yet specialised in these.*

Hypothesis 4b*: The effect of green-tech FDIs (in R&D activities) on the regional capacity to specialise in environmental technologies is greater in regions that are already specialised in these.*

It should be noted that regions that are already specialised in green technologies are not necessarily marked by a higher degree of relatedness in their development than regions that are not yet specialised. Similarly, regions that are not green-tech-specialised do not necessarily develop environmental technologies in a more unrelated manner. The degree of technological relatedness between the environmental technologies in which regions specialise and their pre-existing ones is not pre-determined by the presence of green technologies among the latter and, rather, reflects their co-occurrent use and the similarity of the underlying capabilities (Boschma, 2017).[4]

[4] A green and a non-green technology could draw on more similar capabilities than two green technologies, as inventors could make more frequent concurrent use of the former pair than of the latter. This is what typically happens when new green technologies develop by hybridisation, that is, by recombining available knowledge, green and non-green, as in the notable example of hybrid cars (Zeppini and van den Bergh, 2011).

3 Empirical analysis

3.1 Data

We empirically test our hypotheses through an econometric investigation of 1,050 EU regions (NUTS3 level).[5] To do so, we combine information over the 2003–2014 period from the OECD-REGPAT, fDi Markets (fDi Intelligence, Financial Times), and Eurostat regional statistics databases. From the OECD-REGPAT database, we retrieve the number of patent applications to the European Patent Office (EPO) by inventors residing in each NUTS3 region.[6] In order to measure EIs at the local level, we refer to regional 'green patents' according to the taxonomy (based on the Cooperative Patent Classification, or CPC, and the International Patent Classification, or IPC) recently put forward by the 'OECD-ENVTECH indicator' (Haščič and Migotto, 2015).[7] It is well-known that patents are not free from limitations when used as a measure of EI (Popp, 2005), and their use in capturing the advancements of green technologies has somehow waned in the last decade (EEA, 2020). Still, patents remain the most reliable indicator for systematic empirical analysis of the regional production of technological knowledge (Acs et al., 2002) and have been extensively employed to measure regional green innovation (e.g. Montresor and Quatraro, 2019; Santoalha and Boschma, 2021). One issue that needs to be addressed in the specific case of our analysis is the risk of data-handling truncations due to the delayed publication of patent applications. In this paper, we deal with this by cumulating green patents up to 2014. In order to attenuate patent lumpiness over time, we aggregate information across 3 temporal windows of 4 years each: 2003–2006, 2007–2010; 2011–2014.

[5] As in some cases different NUTS3 regions belong to the same economic system (metropolitan areas), these regions have been aggregated. For a NUTS3-based definition of metropolitan areas, we considered the one adopted by Eurostat and available at https://ec.europa.eu/eurostat/web/metropolitan-regions/background.

[6] We allocate patents to the NUTS3 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.

[7] The OECD-ENVTECH indicator considers 8 broad categories of environmentally related technologies: environmental management; water-related adaptation technologies; climate change mitigation (CCM) technologies related to energy generation, transmission, or distribution; the capture, storage, sequestration, or disposal of greenhouse gases; CCM technologies related to transportation; CCM technologies related to buildings; CCM technologies related to wastewater treatment or waste management; and CCM technologies in the production or processing of goods.

From the fDi Markets database we retrieve the number of greenfield cross-border investment projects located in a certain European city in the 2003–2013 period.[8] Unfortunately, our data do not allow us to capture mergers and acquisitions (M&As) involving foreign investors and incumbent domestic companies. While fDi Markets provides comprehensive information on the distribution of greenfield FDIs by industry (to identify green FDIs) and by functional activity (to identify the specific contribution of R&D FDIs), to the best of our knowledge no data source allows making the same distinctions for M&As. In addition, according to the 2018 World Investment Report over the 2008–2014 period the value (number) of greenfield FDIs was twice (more than twice) as large as the value (number) of net cross-border M&A deals (UNCTAD, 2018, pp. 7–8). Hence, the potential bias introduced by disregarding M&As should not be overemphasized as focusing on greenfield investments allows us to capture a large portion of FDI flows and reassures us about the reliability of our analysis.

Exploiting information on the longitude and latitude of the destination cities for each greenfield FDI project in fDi Markets, it is possible to attribute each investment to the corresponding NUTS3 European region. Furthermore, fDi Markets provides information about the industry in which cross-border investments occur (referring to the NAICS classification) and the functional activity undertaken in each project. Based on this information, we are able to identify green-tech FDIs (as illustrated in Section 3.2.2) and those in R&D vs non-R&D activities.

3.2 Variables and econometric strategy

3.2.1 Dependent variable

Our focal dependent variable is region *i*'s capacity to specialise in 'green technology' at time *t*, $GreenSpec_{it}$. As illustrated above, we have collapsed our data into 3 time periods of 4 years each: 2003–2006; 2007–2010; 2011–2014. Following the previous literature on regional green-tech specialisation/diversification (e.g. Montresor and Quatraro, 2019; Santoalha and Boschma, 2021), we use a dichotomous measure indicating whether a region is specialised in green technologies or not. In a robustness check of our results

[8] fDi Markets is an event-based (or deal-based) database, wherein each entry is a cross-border greenfield investment project for which the provider reports information from several publicly available information sources.

reported in Appendix E, we also use the degree of specialisation (i.e. a continuous rather than dichotomous variable) in green technology, as denoted by the variable $GreenRTA_{it}$ in Eq. (2), as a dependent variable.

Unlike previous studies, which focus on regional technological specialisation in each of the several specific green domains identified by the green patent classification (see above), we refer here to 'green technology' as an encompassing indicator of regional specialisation in green technologies overall. This indicator goes beyond the acquisition of technological advantage in one specific green technology and detects the advantage that a region exhibits in the development of technologies across the entire spectrum of possible green domains.

In analytical terms, $GreenSpec_{it}$ is obtained as a binary transformation of a revealed technological advantage (RTA) indicator that region *i* has in green technology (or not) at time *t* (*GreenRTA*), that is:

$$GreenSpec_{it} = \begin{cases} = 1 \text{ if } GreenRTA_{it} \geq 1, \\ = 0 \text{ otherwise}, \end{cases} \quad (1)$$

where $GreenRTA_{it}$ is defined as follows:

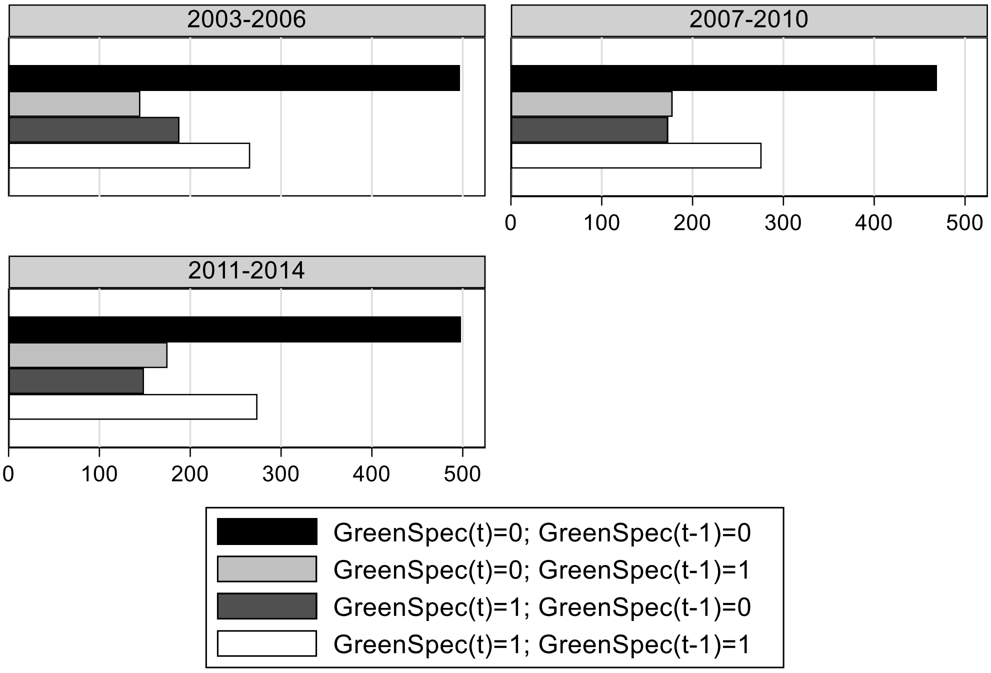
$$GreenRTA_{it} = \frac{\frac{GreenPAT_{it}}{\sum_{i=1}^{n} GreenPAT_{it}}}{\frac{TotPAT_{it}}{\sum_{i=1}^{n} TotPAT_{it}}}. \quad (2)$$

$GreenPAT_{it}$ is the number of (EPO) patent applications made by region *i*'s inventors in any of the IPC and CPC codes that the 'OECD-ENVTECH indicator' considers environmental, and $TotPAT_{it}$ denotes the total number of patents by region *i*. Region *i* is considered specialised in green technology and $GreenSpec_{it}$ is equal to 1 if $GreenRTA_{it}$ is larger than 1, as the region is patenting relatively more (less) in the green domain compared to other regions. Conversely, if $GreenRTA_{it}$ is smaller than 1 $GreenSpec_{it}$ is equal to 0, indicating that region *i* is not specialised in green technology.[9]

Figure 1 reports the number of regions in our sample that, during each and every one of the considered temporal windows (t; t–1) are persistent i) in their green-tech specialisation (GreenSpec(t) = 1; GreenSpec(t–1) = 1) or ii) in their green-tech de-specialisation (GreenSpec(t) = 0; GreenSpec(t–1) = 0), rather than iii) switching towards (GreenSpec(t) = 1; GreenSpec(t–1) = 0) or iv) away from a green-tech specialisation (GreenSpec(t) = 0; GreenSpec(t–1) = 1). It appears that green technology specialisation is a quite persistent trait of EU regions. A large majority of the observed regions were (and remained) non-specialised in their green technology over the 3 considered periods, and the second-largest group is represented by regions that were (and remained) specialised in it. The number of regions that moved across the specialisation threshold is intermediate between the previous groups, with an interesting variation over time. In the first observed period (2003–2006), the number of regions that moved from de-specialisation to specialisation in green-tech is greater than those that moved from specialisation to de-specialisation, while the reverse holds true for the second period (2007–2010), and even more evidently for the third period (2011–2014). Overall, the acquisition of green-tech specialisation ex novo still appears to be a limited phenomenon, which deserves as much attention as the regional capacity to maintain it once it has been established. In order to test Hypotheses 4a and 4b, we explicitly focus on these two different patterns of green-tech specialisation among the results.

[9] As a robustness check, we also consider a more demanding threshold of 1.5 to define specialisation. This means that a region is considered ‘specialised’ if its share of environmental patents over its total patents is 50% larger than the world average.

Figure 1 – Number of regions by *GreenSpec* state (0; 1) in *t* and *t–1*



3.2.2 Explanatory variables

As far as the explanatory variables are concerned, the focal ones refer to the number of cross-border greenfield investment projects by MNEs in a certain region at time *t*. For the sake of simplicity, we refer to measures derived from fDi Markets using the prefix FDI (keeping in mind that these are greenfield investments).

Using these data, we first count the total number of inward FDI projects in the focal region and define the variable FDI_{it}, irrespective of the industries or activities in which they are documented to occur. In order to test Hp1, we then define another variable, $FDI\text{-}Green_{it}$, by counting the number of inward FDI projects that can be considered green tech in a region. As explained in Section 2.1, previous analyses have estimated green FDIs mainly by looking at investments occurring in industries and/or goods and services that can be claimed to improve the environmental sustainability of an economy, either from a supply or a demand perspective, or both. Nevertheless, the list of focal industries compiled on this basis is inevitably exposed to some degree of arbitrariness and has led to heterogeneous outcomes. As has been extensively discussed by Greeninvest (2017) and as summarised in Table 1, this has led to multiple (sometimes conflicting) definitions of green FDI.

Table 1 – Overview of estimates of Green FDIs

Source	Concept	Included	Annual FDI Flow
UNCTAD	Low-carbon FDI	Greenfield FDI in renewable energy, recycling activities, and low-carbon technology manufacturing	US$ 90 billion (2009) US$ 82 billion (2016)
OECD	Green FDI	FDI in environmental goods and services (EGS), proxied by FDI in electricity, gas, and water sectors	US$ 41 billion (2005–2007 average)
		FDI in environmentally relevant sectors from home country with stricter environmental policies or higher energy efficiency than host country	Between US$ 268 and US$ 299 billion (2005–2007 average)
fDi Intelligence	FDI in renewable energy	Greenfield FDI in solar, wind, biomass, hydroelectric, geothermal, marine, and other renewable power generation	US$ 76 billion (2015)
Bloomberg New Energy Finance	Global investment in clean energy, low carbon services, and energy smart technologies	Greenfield and M&A activity in renewables (e.g. biofuels, small hydro, wind, and solar), clean energy services (e.g. carbon markets), and energy smart technologies (e.g. digital energy, energy efficiency, and energy storage)	US$ 287 billion greenfield FDI (2016)

Source: Greeninnvest (2017). UNCTAD: United Nations Conference on Trade and Development.

We contend that a less arbitrary criterion, which is also more consistent with our research questions, can be obtained through a systematic analysis of the technological basis of the industries in which FDIs occur. In particular, we suggest classifying as ‘green-tech FDIs’ those occurring in industries where green technologies are most salient, that is, in industries whose knowledge bases rely significantly on the invention of new environmental technologies. Hence, to be precise we define a measure of *green-tech FDIs*, which is operationalised as follows. We first associate green patents to industries and then define green-tech industries as those that are specialised in green technologies. In practice, we first compute the total number of patent applications worldwide over the 1978–2014 period in any of the green technology classes defined by the ‘OECD-ENVTECH indicator’ (Haščič and Migotto, 2015). Patents are then attributed to NAICS industries by means of their Cooperative Patent Classification (CPC) codes using the ‘algorithmic links with probability’ (ALP) concordance developed by Lybbert and Zolas (2014).[10] We then compute the green RTA for each industry (as in Eq. (2)) and identify

[10] The ALP concordance matches each 4-digit CPC class to one or more industries (with certain probability). The ALP concordance does not aim to a priori identify either the ‘sector of use’ (SOU) or the

as 'green-tech' those industries for which the green RTA is larger than 1. The list of industries specialised in green technologies is reported in Table B1 in Appendix B, and as explained in Section 2.1, this does not need to correspond to the list of the most environmentally friendly industries. Consistent with the previous argument, the variable *FDI-Green*$_{it}$ is defined by the number of inward FDI projects in region *i* that have occurred in any of the identified green-tech industries. For the sake of comparison, this variable will be complemented by *FDI-NGreen*$_{it}$, measuring the number of regional FDIs in industries that do not show a global green-tech specialisation. Both *FDI-Green*$_{it}$ and *FDI-NGreen*$_{it}$ are used as focal regressors in our empirical analysis.

In order to test Hp2, the last set of focal regressors of our analysis is represented by the number of FDI projects that are directed to region *i*, either in green or in non-green-tech industries, classified by functional activity. We distinguish FDIs where the main functional activity is R&D (*FDI-Green-RD*$_{it}$ and *FDI-NGreen-RD*$_{it}$, respectively) versus those in non-R&D activities (*FDI-Green-NRD*$_{it}$ and *FDI-NGreen-NRD*$_{it}$, respectively).[11]

Table B2 reports the top 10 regions by total FDI projects, green-tech FDI projects, and green-tech R&D FDI projects. Figure 2 shows the evolution of our focal regressors along the three considered time periods. The total number of FDI projects directed to our NUTS3 regions has first increased from period 1 to period 2 and then decreased from period 2 to period 3. The deflection of FDIs that we observe may be due to the 2008 financial crisis, reflecting a trend that has been documented on a global scale and for which we control in our econometric estimates (UNCTAD, 2009). The share of green-

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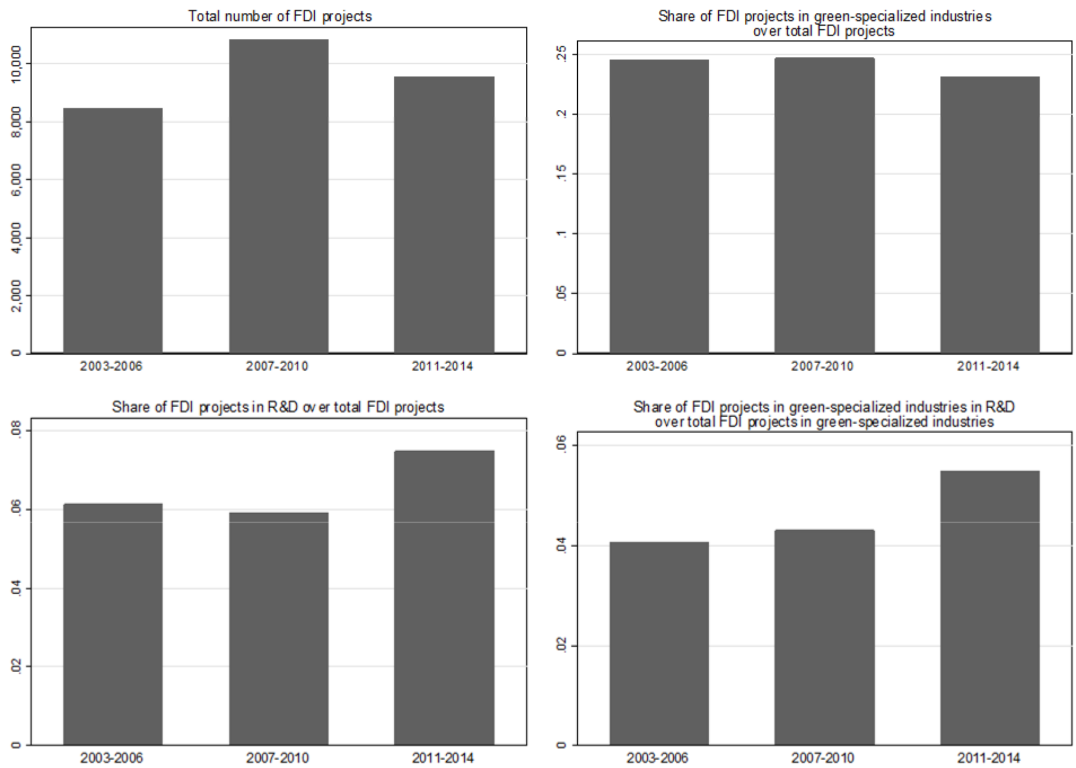
'industry of manufacture' (IOM) of each technology class, as was done by the Yale Technology Concordance (Kortum and Putnam, 1997). However, Lybbert and Zolas (2014) state that 'the weighted ALP approach appears to better fit IOM than SOU results' (p. 538). For what concerns the industry classification, for each NAICS industry in the detailed sub-sector classification of fDI Markets we use the corresponding number of digits in the ALP concordance. For example, some industries in fDI Markets are defined at the 6-digit NAICS level while other industries are defined at the 2-digit NAICS level. As our definition of green technologies is based on a combination of CPC and IPC codes and the ALP concordance is either based on IPC or CPC, we identify at the level of each individual patent whether the patent is green or not and then attribute the green patent to different industries based on its CPC codes, according to the ALP concordance. Regarding the timing of our measurement of industry specialisation, we decided to consider the long-term specialisation pattern, not focusing on year-to-year changes in specialisation in order to avoid noisy changes. Green-technology specialisation is, however, a very persistent phenomenon: the correlation between the time-invariant (1978–2014) industry-level green-tech specialisation variable and the green-tech specialisation variable computed within each time window used in our analysis is always greater than 0.9.

[11] We included in the R&D FDI category those investment projects registered by fDi Markets as dealing with either or both R&D and design, development, and testing.

tech FDIs remained nearly stable from period 1 to period 2 and then slightly decreased from period 2 to period 3, but always around negligible amounts (between 0.2 and 0.25 %). Quite interestingly, the share of regional FDI projects in R&D activities increased both in all and in green-tech industries when the first and the second periods are compared, but the increase was continuous only in the latter case.

Figure 2 – FDI-all and FDI-green projects



3.2.3 Control variables

In investigating the role of the previous focal regressors, we first of all control for a variable that, according to eco-innovation studies, represents the main driver of the development and adoption of new green technologies: the stringency of environmental policies (see Popp et al., 2010, for a review). Even though the focus of our research is not to assess the effectiveness of such policies in driving green technology specialisation, our econometric specification needs to account for environmental policies as they are expectedly correlated with both our dependent variable and our focal regressors.[12] In

[12] For example, Marin and Zanfei (2019) and Noailly and Ryfisch (2015) show that MNEs tend to offshore patents in environmental technologies in countries with more stringent environmental regulations.

order to do this, we first include in our regressions country-by-year dummies, which could account for country-level time-varying changes in environmental policy in a flexible way.

However, even in the presence of homogeneous country-level rules and standards, regions might differ in their exposure to policies, such as in the case of a policy imposing standards on industrial plants to reduce SO_x air emissions. The demand for innovative pollution-abatement equipment could be either high or low, depending on the number of local plants with substantial SO_x emissions and on the total amount of local SO_x emissions. In order to control for this issue, we use regional information on polluting plants and corresponding emissions from the European Pollution Release and Transfer Registry (E-PRTR). We run a principal component analysis, from which we obtain two indicators (the first two components, PC#1 and PC#2) of the regional exposure to environmental policy: 'Exposure to env. policy (PC#1)' and 'Exposure to env. policy (PC#2)' (see Appendix C for further details). With the same aim, we also consider the interaction between these two proxies of regional exposure and a country-level proxy of environmental regulatory stringency, that is, the EPS (Environmental Policy Stringency) indicator developed by the OECD (Botta and Kozluk, 2014).[13]

A second fundamental control that we use in our estimates is the *relatedness* of the technologies that a region already masters to the green technology. As discussed in Section 2.2.2, recent studies in the geography of innovation literature have convincingly shown that regions are more likely to diversify into technological fields that are related to the portfolios of those in which they are specialised (Balland, 2016). Similarly to other technologies, the development of environmental technologies has emerged through a branching process of pre-existing technologies into related fields (Tanner, 2014; Van den Berge and Weterings, 2014; Montresor and Quatraro, 2019; Santoalha and Boschma, 2021). By extending this idea to our analytical approach, which focuses on region *i*'s

[13] 'The OECD Environmental Policy Stringency (EPS) index is a country-specific and internationally comparable measure of the stringency of environmental policy. Stringency is defined as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behaviour. The index ranges from 0 (not stringent) to 6 (highest degree of stringency). […] The index is based on the degree of stringency of 14 environmental policy instruments, primarily related to climate and air pollution' (https://stats.oecd.org/Index.aspx?DataSetCode=EPS). As the indicator is not available for a few newly acceding Eastern European countries (Bulgaria, Estonia, Croatia, Lithuania, Latvia, and Romania), we attribute the average EPS of other newly acceding Eastern European countries for which data is available (Czech Republic, Hungary, Poland, Slovenia, and Slovakia). The rationale is that the evolution of national environmental policy stringency for all of these newly acceding countries is likely to be rather similar as all of these countries had to adopt the EU acquis on environmental policy (Carr and Massey, 2006).

capacity to specialise in a green technology (as we have defined it in Section 3.2.1), our $\textit{Relatedness}_{it,t-1}$ variable offers information on the dyadic cognitive proximity between the green technology at *t* and all technologies in which the region was already specialised in *t*–1 (see Appendix A).[14] As it is usually the case in the extant literature, dyadic proximities between technologies are identified by measuring the co-occurrence of regional RTA in the green technology (see Appendix A for more analytical details about the construction of the variable). As illustrated in Section 2.2, this variable serves to test whether it is more likely that region *i* specialises in green technology at time *t* if at time t–1 it was specialised in technologies with a higher degree of relatedness to green technology itself. Besides using it as a control, in order to test Hp3 $\textit{Relatedness}_{it,t-1}$ is also used as a moderating variable of the effect exerted by our focal FDI regressors on the green-tech specialisation: in econometric terms, this can be done by considering as an additional variable the interaction of FDIs with the relatedness term (FDI-…* $\textit{Relatedness}_{it,t-1}$), which we would expect to have a significant and negative coefficient.

The remaining set of controls is intended to capture the structural features of the sample regions that can be considered salient for our analysis. First of all, in order to account for the local availability of (eco-)innovation inputs, we use Eurostat data (https://ec.europa.eu/eurostat/web/regions/data/database) on regional human capital (share of working-age population with a tertiary degree) and R&D expenditure (total R&D expenditure per capita, in log form). Due to the numerous missing values at the NUTS3 level, these variables have been collected at a more aggregated geographical level of analysis (i.e. NUTS2). Furthermore, given the role that general-purpose technologies have been found to have in the development of green ones (Montresor and Quatraro, 2019), we also retain the regional availability of knowledge in key enabling technologies (KETs)[15] by counting the number of KETs in which regions are specialised (according to the RTA of Eq. (2)). Finally, we control for the size of the focal region in terms of $\textit{GDP}_{it}$ (from Eurostat) and its share of its country's total patents,[16] and for its population density (in log form, based on data from Cambridge Econometrics) to account for the role of

[14] As *t* refers to a 4-year time window (2003–2006; 2007–2010; 2011–2014), *t*–1 refers to 1999–2002, 2003–2006, and 2007–2010, respectively.
[15] We refer to European Commission (2012) for the list of KETs-related IPC classes.
[16] As we include country-by-year dummies, it would be equivalent either to include the share of region's patents or total region's patents in our specification.

agglomeration economies. We also control for the effects of the 2008 crisis by interacting the regional GDP growth in 2007–2009, from Eurostat, with time dummies to account for the possibly persistent impact of the crisis on green-tech specialisation.

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

Table 2 – Descriptive statistics

1,050 EU regions (NUTS3), for three periods: 2003–2006; 2007–2010; 2011–2014.

Variable	Mean	SD	Min.	Max.
GreenSpec	0.40	0.49	0	1
FDI	8.78	32.85	0	665
FDI-Green	2.11	6.67	0	138
FDI-RD	0.57	2.38	0	53
FDI-Green-RD	0.10	0.43	0	6
Exposure to env. policy (PC#1)	0	1.63	-1.18	55.16
Exposure to env. policy (PC#2)	0	1.10	-1.16	11.18
EPS	0.45	0.08	0.24	0.65
Relatedness	0.11	0.04	0	0.35
Share of working-age pop. with tertiary degree, NUTS2	0.25	0.09	0.07	0.51
log(R&D per capita), NUTS2	5.38	1.25	0.92	6.91
KETs	0.43	0.50	0	1
log(GDP)	8.57	1.18	2.25	13.37
Region's share of country patents	0.01	0.02	0	0.38
log(population density)	-2.07	1.10	-6.30	1.60
GDP growth 2007–2009	-0.04	0.10	-0.39	0.27

3.2.4 Econometric strategy

Our baseline specification is the following:

$$GreenSpec_{it} = \phi(\alpha + FDI'_{it}\gamma + X'_{it}\theta + \lambda_{ct} + \varepsilon_{it}), \qquad (3)$$

where FDI'_{it} is the vector of FDI-related variables, X'_{it} is the vector of control variables, λ_{ct} is a series of year-specific country dummies to account for country-level time-varying unobserved features, and ε_{it} is an error term with standard properties.

In order to account for time-invariant unobserved heterogeneity in a flexible way, we include the pre-sample mean of our dependent variable, *GreenSpec*, measured in the 1991–1994 period as an additional control variable (see Blundell et al., 2002, for an illustration of this methodology). In econometric terms, the idea is that the pre-sample mean is a good proxy of time-invariant region fixed effects. Its inclusion also enables us to control for the temporal persistence of the regional green-tech specialisation, which we expect to hold given the path-dependence that technological development usually reveals over time.

In spite of the rich set of controls we have considered, endogeneity remains a concern in our framework. A first source of endogeneity relates to the fact that green-tech FDIs are likely to locate where the pre-conditions for green-tech specialisation were already well developed. Accounting for the 'historical' green-tech specialisation (pre-sample mean) and for the region's relatedness partly addresses this issue. Secondly, it could be the case that the (unobserved) local demand for environmental technologies contributes to green technological specialisation and attracts green-tech FDIs at the same time. We cannot explicitly account for this unobservable component as our only proxy for local demand is GDP. However, as long as local specificities in the demand for green technologies are time-invariant or strongly persistent, the inclusion of the pre-sample mean could also account for this source of endogeneity.

As mentioned in Section 3.2.1, and in line with the literature, our preferred dependent variable is a dichotomous measure of specialisation ($GreenSpec_{it}$). As a consequence, our baseline regressions are estimated using a probit model. However, given the superior methodological tractability of an econometric model using a continuous dependent variable, as a robustness check we also report results based on $GreenRTA_{it}$, using both pooled OLS and panel fixed effects estimators (in Appendix E). In order to test whether results differ with respect to different levels of regional specialisation in green tech, we also run quantile regression estimations.

In an additional set of estimates, the results of which are reported in Appendix F, Eq. (3) is estimated by disentangling the heterogeneity that characterises both green technology and the regions that specialise in it. On the one hand, we consider how our results change by running different estimates for green technologies at different stages of their development, looking at the geographical diffusion and standardisation of the relevant inventive activities (Tables F1 and F2). On the other hand, we also investigate the differences that emerge in terms of our research hypotheses for regions with a relatively low value of four characteristics that are particularly salient in dealing with regional green technologies: i) the economic outcome from the 2008 crisis; ii) population density; iii) country-level environmental regulatory stringency; iv) R&D per capita (Tables F3 and F4). As we argue in Appendix F, this more granular type of analysis enriches our results with interesting nuances.[17]

4 Results

4.1 Control variables

Table 3 reports the results of our baseline estimates. Before moving to our focal regressors, it is interesting to note that regional specialisation in green technology appears to be quite a persistent phenomenon: the pre-sample mean of *GreenSpec* is always significantly positive, suggesting that a history of green-tech specialisations actually matters. More specifically, regions with a green specialisation in 1991–1994 are about 18% more likely to be green-tech specialised in 2003–2014 compared to other regions (14% for specialisation defined as RTA>1.5; see Table D3 in Appendix D for marginal effects).

[17] We thank an anonymous reviewer for having suggested performing this interesting kind of heterogeneity analysis.

Table 3 – Inward FDIs and green-tech regional specialisation – Baseline estimation

Dependent variable: RTA in green technology (dummy)	GreenSpec if RTA>1			GreenSpec if RTA>1.5		
	(1)	(2)	(3)	(4)	(5)	(6)
GreeSpec pre-sample mean (1991–1994)	0.522***	0.520***	0.522***	0.542***	0.540***	0.541***
	(0.0681)	(0.0681)	(0.0681)	(0.0858)	(0.0859)	(0.0861)
Relatedness	5.552***	5.499***	5.564***	5.522***	5.467***	5.545***
	(0.883)	(0.881)	(0.882)	(0.920)	(0.918)	(0.918)
Region's share of country patents	-5.440***	-5.390***	-4.615**	-4.785*	-4.159*	-3.786
	(1.950)	(1.930)	(1.895)	(2.500)	(2.471)	(2.356)
KETs (lag)	0.00958	0.00555	0.00844	-0.0478	-0.0538	-0.0499
	(0.0561)	(0.0562)	(0.0562)	(0.0621)	(0.0623)	(0.0624)
log(GDP)	0.178***	0.169***	0.169***	-0.0419	-0.0542	-0.0594
	(0.0459)	(0.0457)	(0.0455)	(0.0557)	(0.0564)	(0.0563)
Growth 2007–2009 GDP pc	0.0626	0.0719	0.119	-0.636	-0.633	-0.594
	(0.904)	(0.905)	(0.906)	(1.063)	(1.061)	(1.060)
Growth 2007–2009 GDP pc	1.342	1.295	1.336	0.927	0.860	0.933
x D2007–2010	(1.080)	(1.083)	(1.086)	(1.222)	(1.226)	(1.226)
Growth 2007–2009 GDP pc	-0.604	-0.576	-0.576	0.0247	0.0249	0.0585
x D2011–2014	(1.128)	(1.131)	(1.134)	(1.325)	(1.329)	(1.333)
log(pop density)	-0.0148	-0.0154	-0.0162	-0.0210	-0.0212	-0.0213
	(0.0429)	(0.0430)	(0.0430)	(0.0505)	(0.0505)	(0.0506)
log(R&D per capita), NUTS2	-0.108*	-0.110*	-0.108*	-0.155**	-0.159**	-0.159**
	(0.0620)	(0.0620)	(0.0620)	(0.0677)	(0.0677)	(0.0678)
Share of working-age pop. with tertiary degree,	-0.627	-0.569	-0.531	-0.566	-0.447	-0.459
NUTS2	(1.005)	(1.003)	(1.003)	(1.336)	(1.343)	(1.343)
Exposure to env. policy (PC#1)	-0.208	-0.212	-0.206	-0.310*	-0.321*	-0.318*
	(0.153)	(0.154)	(0.153)	(0.179)	(0.181)	(0.180)
Exposure to env. policy (PC#2)	0.122	0.126	0.114	0.202	0.206	0.197
	(0.218)	(0.218)	(0.218)	(0.226)	(0.227)	(0.227)
EPS x Exposure to env. policy (PC#1)	0.491	0.500	0.485	0.769*	0.796*	0.788*
	(0.368)	(0.370)	(0.369)	(0.430)	(0.435)	(0.433)
EPS x Exposure to env. policy (PC#2)	-0.213	-0.224	-0.196	-0.430	-0.445	-0.424
	(0.494)	(0.494)	(0.494)	(0.508)	(0.510)	(0.510)
FDI	0.00000906			-0.00143		
	(0.00110)			(0.00154)		
FDI-Green		0.0173			0.0335**	
		(0.0113)			(0.0132)	
FDI-NGreeen		-0.00407			-0.0117***	
		(0.00285)			(0.00442)	
FDI-Green-RD			0.152**			0.188**
			(0.0718)			(0.0793)
FDI-Green-NRD			0.00738			0.0230*
			(0.0120)			(0.0135)
FDI-NGreen-RD			-0.0660***			-0.0558
			(0.0232)			(0.0370)
FDI-NGreen-NRD			0.000822			-0.00738
			(0.00338)			(0.00497)
Pseudo R^2	0.0943	0.0952	0.0974	0.0919	0.0944	0.0963
N	3054	3054	3054	3015	3015	3015

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

Somewhat surprisingly, the proxies we use to account for the (eco-)innovation inputs of regions (i.e. human capital and KETs) are not significant, with the partial exception of R&D expenditure, which appears to disfavour the green-tech specialisation mainly in the more RTA-demanding specifications (columns 4, 5, and 6). Let us remember, however, that such an effect refers to the direction of the technological efforts undertaken by regions and not to their outcome in terms of innovation performance, which is apparently greater in other non-green technological domains.[18] The propensity to specialise in green technology appears higher for larger regions (in terms of GDP). This advantage disappears when we use a more demanding definition of technological specialisation, however (*GreenRTA*>1.5) (columns 4, 5, and 6). Only slightly more robust across the two RTA thresholds is the significantly negative coefficient for the region's share of country patents. Quite interestingly, the most technologically endowed regions of a country have a lower propensity to specialise in the green-tech domain than the least-endowed ones. This suggests that the acquisition of a revealed green-tech advantage is easier in regions that contribute less to the inventive capacity of a country, and which thus possibly have more degrees of freedom in orienting the direction of technological change in the region. Our proxy of agglomeration economies (population density) turns out to be not significant, possibly because of its blunt nature in capturing a complex phenomenon. Finally, a region's performance around the 2008 financial crisis does not correlate with the region's propensity to specialise in green technologies.

As expected, specialisation in green technology is significantly and positively associated with our indicator of relatedness, which as previously mentioned captures the cognitive proximity between the green technology in which the region specialises and its pre-existing specialisations: in brief, the more related the green technology is to the pre-existing technologies of the region, the higher is its capacity to specialise in it. For what concerns the two proxies of exposure to environmental regulation, instead, they are not different from zero. This result could seem at odds with the broader literature about the relevance of environmental regulation for environmental technology. However, it is

[18] Although an in-depth discussion of these aspects is beyond the scope of this paper, one might venture that these results may also reveal that, on average, regions have historically directed most of their R&D efforts and human capital accumulation to areas other than environmental technologies. This argument is consistent with the fact that attention to environmental issues and to green technology is a relatively recent phenomenon.

worth remembering that the bulk of cross-regional variation in policy stringency comes from country-level regulations and standards, which are already captured by country-year dummies. Quite interestingly, it is the combination of national-level environmental policy stringency and regional exposure to environmental issues (of the first type PC#1) that appears to have a positive and significant impact on green-tech specialisation when using the most restrictive threshold (*GreenRTA*>1.5).

4.2 Regional green-tech specialisation and the nature of FDIs

As far as the effect of FDIs on regional green-tech specialisation is concerned, let us first note that FDIs in industries and functions overall are not correlated with *GreenSpec*: both in column (1) of Table 3, when the *GreenRTA* threshold is set at 1, and in column (4) when it is increased to 1.5. This set of results suggest that regional inward FDIs are likely to be heterogeneous and consist of foreign activities that can have both positive and negative effects on the regional development of environmental technologies, and which can possibly elide each other in the aggregate.

4.2.1 The impact of green-tech FDIs

Columns (2) and (5) of Table 3 instead highlight that the distinction between green-tech and non-green-tech FDIs does actually matter, although the effect of the former is more precisely estimated when *GreenRTA*>1.5. The marginal effects (Table D3 in Appendix D) suggest that, on average, one additional inward green-tech FDI project increases the probability that a region specialises in green tech by nearly 1 percentage point (0.9%); conversely, such a probability reduces by 0.3% for an additional non-green-tech FDI project. This result supports Hypothesis 1 and confirms that MNE investments increase the capacity of hosting regions to master a green technology, providing it occurs in industries where eco-innovation opportunities are relatively high. Indeed, when FDIs occur in industries whose technological base is, instead, non-green, the regional capacity to specialise in green tech diminishes, possibly because it could increase the region's specialisation in industries other than green ones.

4.2.2 The role of the R&D intensity of green-tech FDIs

Columns (3) and (6) show the results of the test for Hypothesis 2, predicting that the functional activity in which FDIs occur also matters. As expected, and confirming

Hypothesis 2, the results suggest that the effect of green-tech FDIs on the regional capacity to specialise in environmental technologies is higher when FDIs are in R&D activities. Indeed, when green-tech FDIs occur in R&D, we find quite a robust correlation with regional specialisation in environmental technologies, regardless of the threshold we set for green-tech specialisation (*GreenRTA*>1 in column 3 or *GreenRTA*>1.5 in column 6). Interestingly, it is the combination of FDIs occurring in green-tech industries and in R&D that seems to make a difference (*FDI-Green-RD*). As we argued in Section 2.1, this could be explained by the fact that when directed towards increasing the research and innovative capacities and outcomes of the investing MNE, FDIs can actually augment the regional capacity to take stock of the eco-innovative opportunities with which green-tech industries are relatively more endowed. This is confirmed by the fact that when they occur in functional activities other than R&D, green-tech FDIs (*FDI-Green-NRD*) are hardly significant in accounting for regional green-tech specialisation.[19] Finally, it should be noted that the average marginal effects (see Table D3 in Appendix D) suggest that the impact of an additional green-tech FDI project in R&D is indeed sizable, increasing the probability of a region specialising in green technologies by about 5 percentage points (5.3% for RTA>1 and 4.9% for RTA>1.5). With respect to generic green-tech FDIs (*FDI-Green*), the same effect did not reach 1 percentage point (0.9%).

Overall, the spectrum of foreign operations through which FDIs can affect the regional capacity to specialise in green tech appears quite circumscribed, not only in terms of the industries in which FDIs occur but also in terms of their functional activities. What is more, regional specialisation in green technology is very sensitive to the nature of FDIs: not only do green-tech FDIs in R&D facilitate its occurrence, but non-green FDIs in R&D disfavour it. In other words, it is likely that R&D FDIs in non-green-tech industries spur innovation in domains that are not green-tech-oriented, thus translating into a lower probability that the region achieves a green technological specialisation.

[19] Integrating the results about Hp1, R&D FDIs in non-green-tech industries (*FDI-NGreen-RD*) show a negative correlation to regional specialisation in environmental technologies, suggesting that such FDIs could contribute to regional specialisation in non-green technologies.

4.3 The moderating role of technological relatedness

In Section 2.2, we highlighted that FDIs and MNEs can be factors and agents of structural change, respectively, as they can introduce more unrelated diversification than local start-ups and incumbents. As noted earlier, this is because MNEs can leverage capabilities from a variety of local contexts in which they are active (including their home regions) and which may differ from that of the host region. In this perspective, MNEs and FDIs become a conduit of capability diffusion across regions, and as we predict in Hypothesis 3, they can be more valuable (in terms of the probability to develop environmental technologies) for regions that were previously specialised in technologies more unrelated to environmental ones. To test Hypothesis 3, we estimate an augmented version of the econometric specifications (3) and (6) of Table 3, in which we include the interaction term between green-tech FDIs in R&D (*FDI-Green-RD*) and the *Relatedness* variable. Consistent with the economic geography literature, this variable measures the average cognitive proximity between the green technology in which regions come to specialise and their pre-existing specialisations. By including this interaction, we can test how *Relatedness* moderates the effect of *FDI-Green-RD* on the green-tech specialisation of regions. Consistent with Hypothesis 3, we expect that the effect exerted on *Green-Spec* (our dependent variable) by the first term of the interaction, *FDI-Green-RD*, is higher for lower values of the second term of the interaction, namely *Relatedness*. In brief, we expect this interaction to be significantly negative. For completeness, in running this additional set of estimates we also include interactions with non-green and non-R&D FDIs.

Table 4 shows that our main variable of interest, the interaction between *FDI-Green-RD* and *Relatedness*, is negative and statistically significant regardless of whether the threshold to identify specialisation is set at RTA>1 or RTA>1.5. This suggests that the effect of green-tech FDI in R&D is higher in regions that were previously specialised in technologies characterised by a relatively high degree of unrelatedness with the green technology. In particular, Figure 3 shows that the marginal effect of *FDI-Green-RD* is positive for regions that at t–1 were specialised in technologies whose relatedness to the green technology is below the median, and that it reaches a maximum for very low relatedness values.

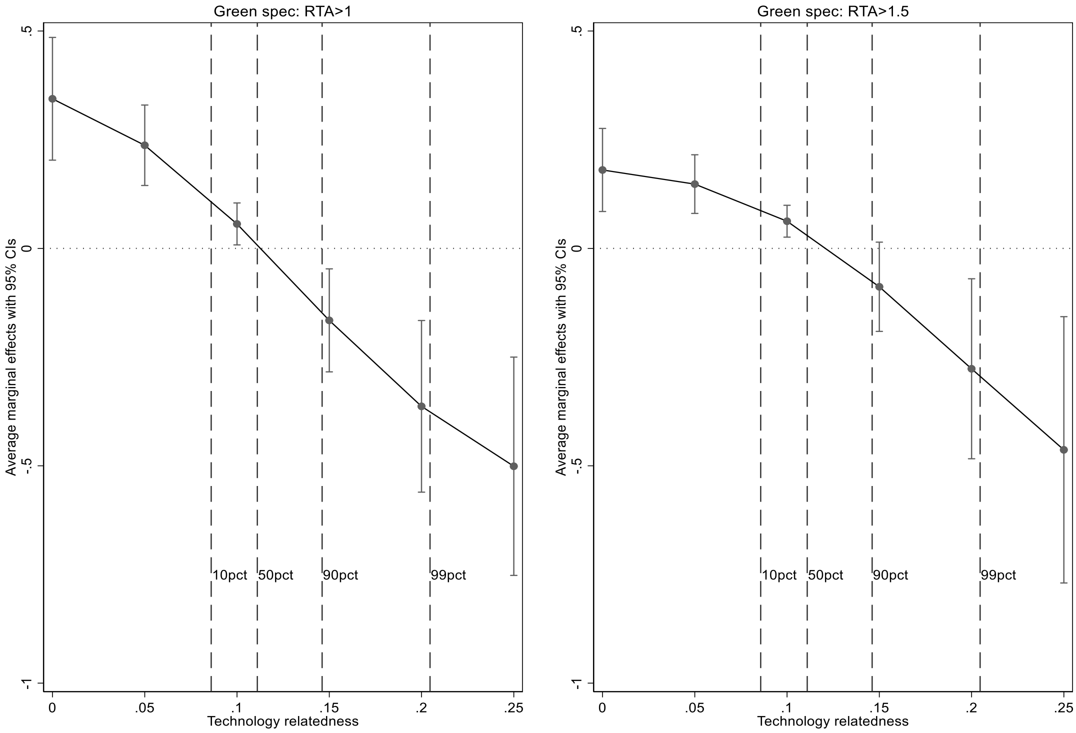
Table 4 – Technological relatedness as a moderating factor of FDI

Dependent variable: RTA in green technology	(1) GreenSpec if RTA>1	(2) GreenSpec if RTA>1.5
Relatedness	6.074***	5.537***
	(0.944)	(0.986)
FDI-Green-RD	1.413***	1.336***
	(0.304)	(0.332)
FDI-Green-NRD	0.000293	0.0186
	(0.0406)	(0.0435)
FDI-NGreen-RD	-0.513***	-0.763***
	(0.129)	(0.216)
FDI-NGreen-NRD	0.0179	-0.00396
	(0.0160)	(0.0226)
FDI-Green-RD x Relatedness	-12.50***	-10.81***
	(3.007)	(3.172)
FDI-Green-NRD x Relatedness	0.0242	-0.00500
	(0.383)	(0.395)
FDI-NGreen-RD x Relatedness	4.252***	6.003***
	(1.203)	(1.772)
FDI-NGreen-NRD x Relatedness	-0.152	-0.00105
	(0.168)	(0.211)
Pseudo R^2	0.103	0.103
N	3054	3015

Probit model. Observations: NUTS3 regions for three periods (2003–2006; 2007–2010; 2011–2014). Additional variables: country-by-year dummies, GreeSpec pre-sample mean (1991–1994), relatedness, region's share of country patents, KETs (lag), log(GDP), GDP growth in 2007–2009 interacted with time dummies, log(pop density), log(R&D per capita) of NUTS2, share of NUTS2 working-age population with tertiary degree, exposure to env. policy (PC#1), exposure to env. policy (PC#2), EPS x exposure to env. policy (PC#1), EPS x exposure to env. policy (PC#2). Standard errors clustered by region in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

The above results support Hypothesis 3 and suggest that green FDIs in R&D bring external knowledge that allows the region to take a larger leap from technologies relatively more unrelated to the green tech. A different way to interpret this finding is that in the absence of R&D green FDI, regions specialise in environmental technologies mainly when the pre-existing knowledge base of the region is highly related to the green tech, according to previous evidence about the place dependence of specialisation in environmental technologies (Montresor and Quatraro, 2019). In other words, without the FDIs at stake, it is unlikely that regions specialised in technologies unrelated to green technologies would be able to acquire a specialisation in environmental technologies. Hence, green-tech FDIs in R&D can indeed act as agents of structural change into green technologies unrelated to previous specialisations.

Figure 3 – Average marginal effects of *FDI-Green-RD* for different levels of relatedness



4.4 Acquiring the green-tech specialisation ex novo vs maintaining it over time

As argued in the second part of Section 2.2, we expect that FDIs (of a certain kind) may also play a role in the acquisition/persistence of the green-tech specialisation of regions. In particular, according to Hypothesis 4a we might expect that FDIs, in exposing regions to new knowledge sources and technological opportunities, could make green-tech specialisation less path dependent. However, as spelled out in Hypothesis 4b, local firms, industrial systems, and institutions exposed to new technological opportunities in green domains tend to exhibit some rigidities and a lack of capacity to absorb and recombine the new knowledge transferred via FDIs. These rigidities and resistance to change can eventually lead to reinforcing pre-existing green-tech specialisations rather than achieving ex novo specialisation in environmental technologies.

In addressing these research hypotheses, Table 5 reports the effects exerted by FDI variables in the estimates of Eq. (3) distinguishing between regions that were and were not specialised in green technologies at *t–1* (Table D4 in Appendix D reports the average marginal effects).[20]

Significant effects of FDIs on regional specialisation in environmental technologies emerge almost exclusively with respect to regions that are already specialised in green technologies (in *t–1*). In contrast, FDIs do not help non-green-tech-specialised regions to acquire a green-tech specialisation ex novo, and Hypothesis 4b is thus supported. More generally, all of the effects we detected in Table 3 without distinguishing the green-tech starting points of regions vanish with respect to non-specialised ones. Although very weakly significant, the only exception is represented by non-green FDIs in R&D, which make non-specialised regions less likely to specialise in green technologies (*FDI-NGreen-RD* is negative for the regions at stake, although for the lower threshold only).

Overall, the results regarding non-green-tech-specialised regions suggest that pre-existing experience in green technology is a necessary condition for the knowledge and competencies brought by inward (green-tech, R&D) FDIs to have an effect, namely in keeping and/or reinforcing the relevant specialisation. In brief, FDIs do not relieve regions of the weight of path-dependence in developing green technologies.

The findings illustrated in Table 5 suggest that if a region already has a specialisation in green technologies and thus has potentially acquired a greater capacity to absorb green-tech knowledge from outside, it is in a better position to take advantage of green FDIs in maintaining a specialisation in environmental technologies. In other words, the strict spectrum of foreign operations that affect regional green-tech specialisation in general becomes wider when regions are already specialised in environmental technologies and are thus well placed to absorb relevant knowledge through FDIs so as to maintain and even reinforce their specialisation.

When already specialised regions are considered, the results regarding the effect of non-green FDIs take on some interesting nuances as well. Not only does *FDI-NGreen* reduce a region's capacity to maintain the green-tech specialisation that it had previously acquired (though for the higher RTA threshold only), as expected and consistent with Table 3, but the same is also true for non-green FDIs in activities other than R&D (*FDI-*

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[20] Additional variables and dummies are not reported, but the relevant estimates are consistent and available from the authors upon request.

NGreen-NRD is significantly negative, though for the higher RTA threshold only). A possible explanation for this result is that foreign non-green-tech operations induce a region to target alternative non-green technologies and that this occurs also (and especially) when these are non-innovative operations. Quite symmetrically, in the case of green-tech FDIs it is not only R&D FDIs that reinforce the green-tech specialisation of regions that are already specialised in environmental technologies. Green-tech FDIs in activities other than R&D appear to have an effect in the same direction as well, although with a lower impact than in the case of green-tech FDIs in R&D.

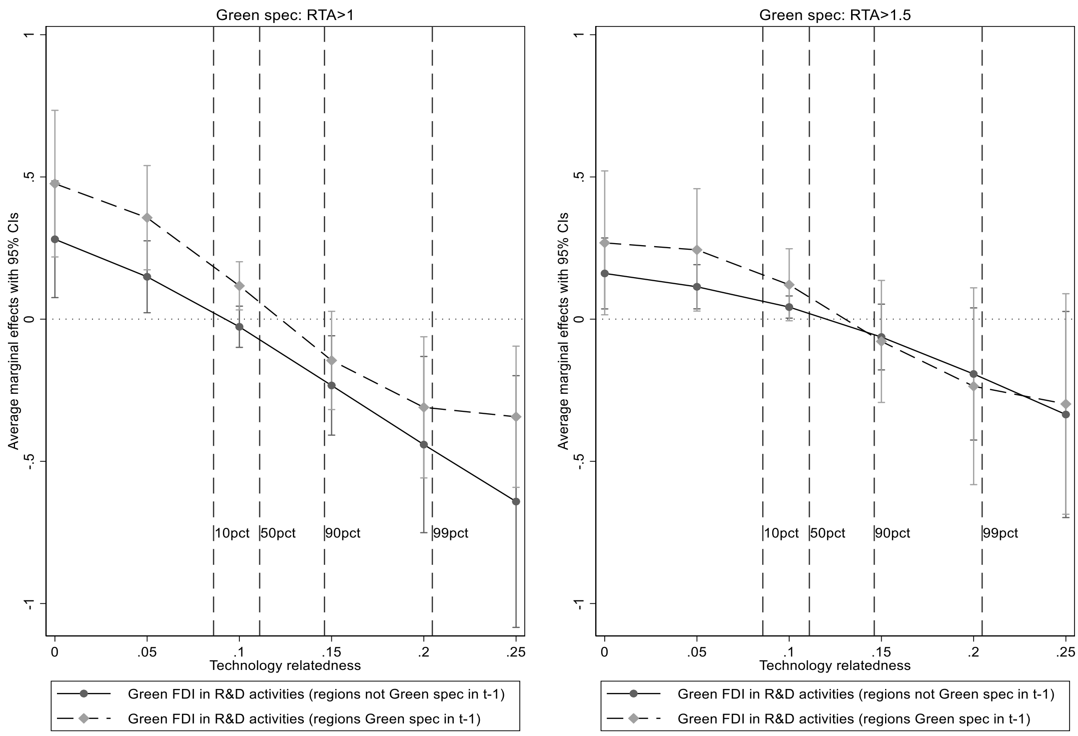
Table 5 – Persistence vs ex-novo acquisition of regional green-tech specialisation

Dependent variable: RTA in green technology (dummy)	GreenSpec if RTA>1		GreenSpec if RTA>1.5	
	(1)	(2)	(3)	(4)
FDI-Green	-0.00948		0.00757	
(*Non-green specialised regions*)	(0.0146)		(0.0144)	
FDI-Green	0.0477***		0.137***	
(*Green specialised regions*)	(0.0182)		(0.0307)	
FDI-NGreen	-0.00679		-0.00802	
(*Non-green specialised regions*)	(0.00450)		(0.00596)	
FDI-NGreen	-0.00587		-0.0327***	
(*Green specialised regions*)	(0.00459)		(0.00889)	
FDI-Green-RD		-0.102		0.116
(*Non-green specialised regions*)		(0.124)		(0.0967)
FDI-Green-RD		0.311***		0.487**
(*Green specialised regions*)		(0.119)		(0.191)
FDI-Green-NRD		-0.00877		-0.00176
(*Non-green specialised regions*)		(0.0165)		(0.0142)
FDI-Green-NRD		0.0331*		0.114***
(*Green specialised regions*)		(0.0190)		(0.0338)
FDI-NGreen-RD		-0.0731*		-0.0625
(*Non-green specialised regions*)		(0.0426)		(0.0460)
FDI-NGreen-RD		0.00194		0.0393
(*Green specialised regions*)		(0.0458)		(0.0878)
FDI-NGreen-NRD		-0.00166		-0.00243
(Non-green specialised regions)		(0.00649)		(0.00566)
FDI-NGreen-NRD		-0.00479		-0.0322***
(Green specialised regions)		(0.00561)		(0.0123)
Pseudo R^2	0.108	0.111	0.104	0.107
N	3054	3054	3015	3015

Probit model. Observations: NUTS3 regions for three periods (2003–2006; 2007–2010; 2011–2014). Additional variables: country-by-year dummies, *GreeSpec* pre-sample mean (1991–1994), relatedness, region's share of country patents, KETs (lag), log(GDP), GDP growth in 2007–2009 interacted with time dummies, log(pop. density), log(R&D per capita) of NUTS2, share of NUTS2 working-age population with tertiary degree, exposure to env. policy (PC#1), exposure to env. policy (PC#2), EPS x exposure to env. policy (PC#1), EPS x exposure to env. policy (PC#2). Standard errors clustered by region in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

As a final step in our analysis, Figure 4 reports the average marginal effects of *FDI-Green-RD* by considering the moderating role played by technological relatedness in regions that were and were not already specialised in a green technology.[21] Confirming previous results in Table 4, the largest marginal effect of green-tech R&D FDIs is observed in regions that were already specialised in green-technologies (dashed lines), provided the regional portfolio of pre-existing technological specialisations was relatively unrelated to the green tech: this further confirms Hypothesis 3.

Figure 4 – Average marginal effects of Green *FDI in R&D* for different levels of relatedness: green vs non-green specialised (in t–1) regions



A new important result emerges with respect to what we found in Table 4, however, where the effect of *FDI-Green-RD* on the green-tech specialisation of non-specialised regions was not significant. Provided that relatedness is very low (approximately below the 10th percentile), green FDIs in R&D now positively correlate also with the regional capacity to acquire a green-tech specialisation ex novo (solid lines). Quite interestingly, this effect

[21] Marginal effects of *FDI-NGreen-RD* conditional on different values of relatedness are available upon request.

materialises exclusively with respect to green technologies that are less bounded by the place-dependent effect of relatedness. In other words, the only case in which *FDI-Green-RD* facilitates the acquisition of ex-novo regional green-tech specialisation is when this green technology is largely unrelated to pre-existing ones. On the basis of these results, it seems that experience in green technology is nearly always a necessary pre-condition for FDIs to facilitate the relevant specialisation and for them to facilitate a more unrelated access to the same technology. The only case in which this pre-condition vanishes is when the relatedness of the green technology to pre-existing (non-green-tech) ones is really low. For specialisation in really distant green technologies (i.e. unrelated in cognitive terms), having had experience in these is no more decisive and FDIs can help regions do it ex novo. Still, the effect of the FDIs at stake remains larger for already specialised regions, wherein foreign investments appear to help maintain and even reinforce the pre-existing green-tech specialisation over time. Hence, Hypothesis 4b remains supported.

4.5 Robustness checks and additional analyses

To complement our main results, we perform a number of robustness checks concerning our measure of technological specialisation in green technologies and our estimation methods, and we provide additional analyses of the role of technological and regional heterogeneity. The results are reported in a set of additional Appendices.

First, in Appendix E we use *GreenRTA* instead of *Green-Spec* as our dependent variable. This allows us to test the robustness of our results to a more fine-grained (not dichotomous) measure of technological specialisation. The results, using pooled OLS estimation, are presented in Table E1 and support our main findings that green-tech FDIs have a positive, although imprecisely estimated, effect on *GreenRTA* (Hp 1); furthermore, it is R&D FDIs in green-tech industries that have a positive effect on the same dependent variable (Hp 2). Table E2 provides evidence of the moderating role of relatedness (Hp 3), which is again in line with our baseline estimation. Finally, Tables E3 and E4 report the results by distinguishing previously and not previously specialised regions in green technology and confirm the conditioning role of the pre-existence of the same specialisation, except for low levels of relatedness. Still, the effect of FDIs is greater for the maintenance than the ex-novo acquisition of a regional green-tech specialisation, and Hypothesis 4b remains supported.

It should be noted that an estimation with regional fixed effects, which was not possible in the non-linear (probit) framework, yields results that are remarkably similar to the pooled OLS estimation. This can be interpreted as evidence that the pre-sample mean of *GreenSpec* is actually capturing the relevant unobserved heterogeneity. In Figure E1, we present the results of a quantile regression, which show that the effects of green-tech FDI in R&D (top-left graph) is positive throughout the distribution of *GreenRTA*, although the effects are more precisely estimated around the median.

In Appendix F, we report and discuss the results obtained by running our estimates for different kinds of environmental technologies and different types of specialising regions. We refer the reader to the same Appendix for details, but suffice to say here that Table F1 shows that our main results hold irrespective of the maturity of environmental technologies. However, important differences emerge by looking at marginal effects in Table F2. In particular, the impact of green FDIs in R&D on regional green-tech specialisation is almost twice as large for more mature environmental technologies compared to less mature ones.

As for the heterogeneity across types of regions, we have focused on four differentiating characteristics that are particularly salient in dealing with regional green technologies. Table F3 shows that green FDIs in R&D exert a significantly positive effect on green-technology specialisation in regions i) that showed more resilience to the 2008–2009 recession; ii) that are more densely populated; iii) in countries with relatively more stringent environmental regulation; iv) with a high level of R&D intensity.

5 Conclusions

This paper investigates the extent to which FDIs can contribute to regional specialisation in green technology. While the relevance of green technologies for increasing environmental sustainability has been largely documented, both at the national and at the sub-national level, the theoretical approach through which their regional development has been investigated so far largely relies on the recombinant-innovation approach, where the endowment of local knowledge is pivotal and the contribution of external knowledge brought into regions by non-local actors is still relatively unexplored. This is particularly the case for the role of FDIs and MNEs. By combining different streams of literature, we first investigate whether and to what extent the nature of FDIs contributes to regional green-tech specialisation. In particular, we study how green-tech specialisation is affected by FDIs accruing to industries that are more or less prone to innovating in environmental domains and by R&D-intensive FDIs. Second, we explore the role of FDIs in facilitating specialisation in green technologies in industries that are more cognitively distant from pre-existing ones. Finally, we analyse whether in light of their being factors of structural change, FDIs can also facilitate the persistence of existing green-tech specialisations or favour the acquisition of green technologies ex novo.

Through an original combination of different datasets, we have addressed these issues on a systematic basis with respect to a large sample of European regions at a quite disaggregated level of analysis (i.e. NUTS3) over the 2003–2014 period. Our results show that inward greenfield FDIs can have a significant effect on regional green-tech specialisation. This effect is mostly driven by FDIs involving R&D activities and occurring in industries where green technologies play a salient role, however. The same effect emerges more strongly in regions whose knowledge base is marked by a low level of relatedness to green technology. However, unless this technological relatedness is very low, green-tech FDIs in R&D do not facilitate the ex-novo acquisition of green technology but, rather, help already specialised regions maintain a green-tech specialisation over time.

Our results are robust to different parametrisations of our dependent variable (binary or continuous) and estimation methods (probit, OLS, and quantile regression). Quite interestingly, the relationships that we have identified between green-tech FDIs in R&D and regional specialisation in environmental technologies appear robust across different vintages of technologies along their lifecycle. In addition, we found that the impact of green-tech FDIs in R&D differs according to specific characteristics of regions, such as population density, R&D intensity, resilience to economic crises, and being located in countries with highly stringent environmental regulations.

These results have important implications in terms of both academic research and policy. As for the former, we suggest that FDIs can contribute to the greening of a region’s technologies and, possibly, to a more sustainable local development. This confirms the need to enrich the recombinant-innovation approach to the geography of green technologies with the consideration of knowledge sources that are external to regions

(Boschma, 2017; Balland and Boschma, 2021). On the other hand, we have found that the foreign injection of knowledge and capabilities that can help regional green-tech specialisation operates only through a restricted set of foreign operations: FDIs occurring in specific industries (highly prone to innovation in green domains) and involving specific functions (R&D). Thus, we suggest that the progress in the combination of innovation geography and international business studies should proceed by adopting a highly granular approach. It is not only the nature of technologies that matters, but also the characteristics of the FDIs that they receive. Moreover, we also observe that while the FDIs at stake facilitate the acquisition of a green-tech specialisation more markedly in regions with technologies more cognitively distant from the green tech, they are mainly able to do so in regions that are already green-tech-specialised. On the one hand, the role of FDIs in intervening in and possibly helping to recombine local knowledge for the sake of green-tech specialisation is facilitated by the presence of technological knowledge cognitively unrelated to this specialisation, and with respect to which there are more cognitive degrees of freedom in the recombination. On the other hand, unless this unrelatedness is very great, the pre-existence of green-tech knowledge appears to be a necessary condition for the recombination of unrelated local knowledge in the same domain. This suggests that when it comes to regional specialisation in a green technology, the ascertained role of MNEs as actors of structural change faces some cognitive trade-offs, regarding which further research is needed.

In terms of policy, our results suggest that the promotion and selection of FDIs and support for the entrance of MNEs in a region could, in principle, be important policy tools for facilitating the local development of green technologies, which are crucial to increasing environmental sustainability. However, the insertion of policy measurements for inward FDIs into the toolbox of regional environmental policies should occur with extreme care, by considering on the one hand the industry and the functional nature of FDIs, and on the other hand the cognitive proximity and the technological experience on which the local development of green tech can rely. Because of this, combining the channels of international business connectivity with the features of the local knowledge base appears to be a fundamental policy challenge to deal with in order to facilitate Smart Specialisation Strategies for Sustainability (S4) (https://s3platform.jrc.ec.europa.eu/s4). The heterogeneous effects that we have detected across regions of different kinds also suggest that, as usual, policy support for the relationship at stake should be evidence-based and context-specific.

We are conscious that our work is not free from limitations, mainly due to aspects that we have not explicitly considered in the analysis and on which future research could focus. First, more conceptual and refined empirical work is required to disentangle the extent to which our results reflect the inventive activities of MNE subsidiaries located in particular regions—direct effects—rather than the spillovers they have on the local firms with which they interact along the value chain—indirect effects. Second, a more granular spatial analysis is needed to investigate the extent to which the indirect effects of FDIs concentrate in the hosting regions or distribute across neighbouring ones. Third, the integration of additional datasets could help disentangle whether the results we obtained with respect to greenfield FDIs extend to the consideration of mergers and acquisitions (M&As). Fourth, from a methodological point of view, future research should concentrate on the adoption of more flexible models (both parametric linear models and semiparametric additive models) to address the true process that is generating the data (DGP) that we use, an endeavour that could benefit from recent econometric research on this topic (e.g. Musolesi and Mazzanti, 2014; Mazzanti and Musolesi, 2020). Finally, future research avenues could involve more precisely identifying the role of MNE strategies in determining their effects on regional specialisation, distinguishing the degree of economic development and the technological profiles of the FDI home countries, and considerng their matching with those of the hosting regions. This is just a limited set of open issues for the analysis of which our results can hopefully provide a useful starting point.

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Greenfield Foreign Direct Investments and Regional Environmental Technologies

Online Appendix

Appendix A – Definition of green technologies, green specialisation, and relatedness

We follow the recent literature (e.g. Montresor and Quatraro, 2019) in the construction of our indicator of technology relatedness. For each technology class *k* and time window *t* we first compute the RTA for each NUTS3 region (all world countries) *i* as follows:

$$RTA_{it}^{k} = \frac{Pat_{it}^{k} / \sum_k Pat_{it}^{k}}{\sum_i Pat_{it}^{k} / \sum_i \sum_k Pat_{it}^{k}}$$

where Pat_{it}^{k} represents the count of EPO patents in region *i*, time window *t* and technology class *k*. Technologies are defined in terms of 4-digit CPC classes. As our interest here is on green technologies as a whole, we consider them all as constituting a single technology meta-class: this means that out of a total number of *K* technology classes, there are *K-1* that are non-green 4-digit CPC classes, and there is *one* green technology meta-class (that comprises more than one green CPC 4-digit classes). The dependent variable used in the text, $GreenSpec_{it}$ is set to be equal to 1 (0), if RTA_{it}^{k} calculated for the meta-class of green technologies is larger than 1 (between 0 and 1). For each time period, we then identify $GreenProximity_{t}^{k}$ as an average measure of co-occurrence across all regions of $GreenSpec_{it}^{k}$, and of specialisations in each of the other technology classes ($Spec_{it}^{k}$). .

Finally, we define our measure of relatedness for region *i* in time window *t* as the combination of technology specializations in time window *t-1* ($Spec_{it-1}^{k}$) and the proximity between technology *k* and green technologies in time windows *t* ($GreenProximity_{t-1}^{k}$):

$$Relatedness_{it} = \frac{1}{K} \sum_{k} GreenProximity_{t}^{k} \times Spec_{it-1}^{k}$$

Appendix B – Definition of green specialized industries

Table B1 – Subsectors with Green RTA>1

Subsectors (NAICS-based fDI Markets classification)	Green RTA
Iron ore mining	8.03
Other (Consumer Electronics)	7.58
Copper, nickel, lead, & zinc mining	7.35
Batteries	7.07
Computer facilities management services	6.67
Water, sewage & other systems	6.67
Waste management & remediation services	6.53
Scenic & sightseeing transport	6.26
Motor vehicle electrical & electronic equipment	6.17
Natural, liquefied and compressed gas	6.11
Semiconductor machinery	5.94
Other metal ore mining	5.53
Gold ore & silver ore mining	5.53
Communications equipment	4.74
Motor vehicle gasoline engines & engine parts	4.68
All other electrical equipment & components	4.18
Coal mining	3.77
All other electrical equipment & components	3.51
Light trucks & utility vehicles	3.43
Heavy duty trucks	3.43
Motor vehicle stamping	3.38
Household appliances	3.14
Wind electric power	2.88
Other electric power generation (Alternative/Renewable Energy)	2.88
Biomass power	2.88
Geothermal electric power	2.88
Hydroelectric power	2.88
Marine electric power	2.88
Solar electric power	2.88
Power transmission equipment	2.84
Other (Engines & Turbines)	2.84
Engines & Turbines	2.84
Petroleum refineries	2.79
Aircraft engines, other parts & auxiliary equipment	2.69
Electrical equipment	2.62
Lime & gypsum products	2.45
Pipeline transportation of natural gas	2.41
Other (Space & Defence)	2.41
Other non-metallic mineral products	2.34
Nonmetallic mineral mining & quarrying	2.34
Heavy & civil engineering	2.28
Air transportation	2.25
Other (Aerospace)	2.20
Boiler, tank, & shipping container	2.14
Other pipeline transportation	2.11
Oil & gas extraction	2.06
Clay product & refractory	1.99
Pipeline transportation of crude oil	1.98
Motor vehicle transmission & power train parts	1.95
Railroad rolling stock	1.95
Aircraft	1.93
Ships & boats	1.77
Forging & stamping	1.76

Subsectors (NAICS-based fDI Markets classification)	Green RTA
Iron & steel mills & ferroalloy	1.73
Measuring & control instruments	1.67
Navigational instruments	1.67
Animal production	1.63
Other (Minerals)	1.58
Other (Building & Construction Materials)	1.58
Other (Ceramics & Glass)	1.58
General purpose machinery	1.57
Crop production	1.54
Ventilation, heating, air conditioning, and commercial refrigeration equipment manufacturing	1.51
Advertising, PR, & related	1.48
Automobiles	1.43
Bakeries & tortillas	1.42
Guided missile & space vehicles	1.42
Basic chemicals	1.41
Residential building construction	1.34
Support activities for transportation	1.33
Other (Transportation)	1.33
Freight/Distribution Services	1.33
Plastic bottles	1.29
Glass & glass products	1.28
Support activities for mining & energy	1.20
Support Activities for Mining	1.20
Spring & wire products	1.17
Transit & ground passenger transportation	1.15
Fishing, hunting & trapping	1.13
Agriculture, construction, & mining machinery	1.12
Cement & concrete products	1.11
Electric lighting equipment	1.08
Other (Metals)	1.07
Other fabricated metal products	1.07
Animal food	1.06
Soft drinks & ice	1.03

Table B2 – Number of FDI project by receiving region (top 10 by category; years 2003-2014)

All projects		
NUTS code	Region	N of FDI projects
FR001MC	Paris	1830
IE001MC	Dublin	913
ES001MC	Madrid	869
ES002M	Barcelona	779
DE005M	Frankfurt am Main	663
RO001MC	Bucuresti	643
DE003M	München	605
BE001MC	Bruxelles / Brussel	541
DE001MC	Berlin	513
DE011M	Düsseldorf	511
Projects in green specialized industries (all activities)		
NUTS code	Region	N of FDI projects
FR001MC	Paris	329
ES001MC	Madrid	166
ES002M	Barcelona	165
RO001MC	Bucuresti	137
DE011M	Düsseldorf	130
SK001MC	Bratislava	118
DE005M	Frankfurt am Main	112
BE001MC	Bruxelles / Brussel	109
DE003M	München	104
BG001MC	Sofia	104
Projects in green specialized industries (R&D activities)		
NUTS code	Region	N of FDI projects
ES002M	Barcelona	13
FR001MC	Paris	11
DE007M	Stuttgart	8
BE001MC	Bruxelles / Brussel	8
UK025M	Coventry	7
IT004M	Torino	7
UK002M	West Midlands urban area	7
DE002M	Hamburg	5
DE038M	Ruhrgebiet	5
UK016M	Aberdeen	5

Appendix C – Proxies for the regional exposure to environmental regulation

A detailed source of information about polluting emissions of industrial plants is the European Pollution Release and Transfer Registry (E-PRTR), maintained by the European Environment Agency. The database collects information on air, land and water polluting emissions for over 30,000 industrial installations across Europe and for 91 key pollutants. Industrial installations are requested to disclose information about polluting emissions for those pollutants that exceed pollutant-specific thresholds. The data collection was established in 2007. However, the predecessor of E-PRTR, that is the EPER database (European Pollution Emission register), reports very similar information for years 2001 and 2004. We attribute industrial installations to regions by means of geographic coordinates available in the database.

As a first set of variables, we consider the 'extensive margin', that is the number of industrial installations with at least one air or water pollutant exceeding the threshold. We rescale these variables by regional GDP to account for the size of the region.

A second set of variables accounts for the 'intensive margin', for which we consider the total level of emissions by installations exceeding the thresholds for CO2, NOx and SOx air emissions. We select these three pollutants as they are the most common pollutants for industrial combustion facilities and they are subject to stringent EU and national regulations and standards.

To ease interpretation and focus on a small number of variables of exposure, we perform a principal component analysis (PCA). Based on the usual rule-of-thumb of retaining principal components with eigenvalues above unity, we obtain two principal components, accounting for 77 percent of the overall variance. Factor loadings for the two components are reported in Table C1. The first component is representative of emission intensities (intensive margin) while the second components has high positive factor loadings for the two variables that describe the intensive margin.

Table C1 – Principal component analysis on measures of regional exposure to environmental regulation

Expoxure variable	PC#1	PC#2
N of facilities with at least 1 air pollutant above threshold / GDP	-0.0663	0.8465
N of facilities with at least 1 water pollutant above threshold / GDP	0.1949	0.5299
CO2 emissions of establishments / GDP	0.5798	-0.0342
NOx emissions of establishments / GDP	0.5804	-0.016
SOx emissions of establishments / GDP	0.5335	-0.0339

The table reports factor loadings of rotated principal components. Eigenvalue #1: 2.84; eigenvalue #2: 1.02; eigenvalue #3: 0.65. Cumulative share of explained variance of the two principal components: 0.77.

Appendix D – Descriptive statistics, additional estimation tables and average marginal effects

Table D1 – Average marginal effects for Table 3

Dependent variable: RTA in green technology (dummy)	GreenSpec if RTA>1			GreenSpec if RTA>1.5		
	(1)	(2)	(3)	(4)	(5)	(6)
GreeSpec pre-sample mean (1991-1994)	0.183***	0.182***	0.183***	0.142***	0.141***	0.141***
	(0.0228)	(0.0228)	(0.0228)	(0.0220)	(0.0220)	(0.0220)
Relatedness	1.950***	1.930***	1.947***	1.441***	1.424***	1.441***
	(0.305)	(0.304)	(0.304)	(0.238)	(0.237)	(0.237)
Region's share of country patents	-1.911***	-1.891***	-1.615**	-1.249*	-1.083*	-0.984
	(0.684)	(0.676)	(0.662)	(0.654)	(0.644)	(0.613)
KETs (lag)	0.00337	0.00195	0.00295	-0.0125	-0.0140	-0.0130
	(0.0197)	(0.0197)	(0.0197)	(0.0162)	(0.0162)	(0.0162)
log(GDP)	0.0624***	0.0593***	0.0590***	-0.0109	-0.0141	-0.0154
	(0.0160)	(0.0159)	(0.0158)	(0.0145)	(0.0147)	(0.0146)
Growth 2007-2009 GDP pc	0.109	0.110	0.131	-0.0828	-0.0876	-0.0680
	(0.221)	(0.220)	(0.219)	(0.200)	(0.198)	(0.196)
log(pop density)	-0.00519	-0.00539	-0.00565	-0.00547	-0.00553	-0.00554
	(0.0151)	(0.0151)	(0.0151)	(0.0132)	(0.0131)	(0.0131)
log(R&D per capita), NUTS2	-0.0379*	-0.0385*	-0.0379*	-0.0405**	-0.0413**	-0.0413**
	(0.0217)	(0.0217)	(0.0217)	(0.0176)	(0.0176)	(0.0176)
Share of working age pop with tertiary degree, NUTS2	-0.220	-0.200	-0.186	-0.148	-0.116	-0.119
	(0.353)	(0.352)	(0.351)	(0.348)	(0.350)	(0.349)
Exposure to env policy (PC#1)	0.00465	0.00475	0.00440	0.00931	0.00943	0.00931
	(0.00748)	(0.00748)	(0.00747)	(0.00638)	(0.00636)	(0.00635)
Exposure to env policy (PC#2)	0.00914	0.00875	0.00911	0.00237	0.00163	0.00189
	(0.0109)	(0.0109)	(0.0108)	(0.00902)	(0.00901)	(0.00904)
FDI	0.00000318			-0.000372		
	(0.000386)			(0.000402)		
FDI-Green		0.00607			0.00873**	
		(0.00397)			(0.00343)	
FDI-NGreeen		-0.00143			-0.0031***	
		(0.000999)			(0.00115)	
FDI-Green-RD			0.0531**			0.0488**
			(0.0251)			(0.0206)
FDI-Green-NRD			0.00258			0.00597*
			(0.00420)			(0.00350)
FDI-NGreen-RD			-0.0231***			-0.0145
			(0.00810)			(0.00962)
FDI-NGreen-NRD			0.000288			-0.00192
			(0.00118)			(0.00129)

Average marginal effects from probit model (see Table 3). Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Table D4 – Average marginal effects for Table 4

Dependent variable: RTA in green technology (dummy)	GreenSpec if RTA>1		GreenSpec if RTA>1.5	
	(1)	(2)	(3)	(4)
FDI-Green	-0.00328		0.00192	
(*Non-green specialised regions*)	(0.00505)		(0.00366)	
FDI-Green	0.0167***		0.0368***	
(*Green specialised regions*)	(0.00631)		(0.00812)	
FDI-NGreen	-0.00235		-0.00204	
(*Non-green specialised regions*)	(0.00155)		(0.00151)	
FDI-NGreen	-0.00206		-0.00876***	
(*Green specialised regions*)	(0.00160)		(0.00234)	
FDI-Green-RD		-0.0351		0.0294
(*Non-green specialised regions*)		(0.0429)		(0.0245)
FDI-Green-RD		0.109***		0.131**
(*Green specialised regions*)		(0.0412)		(0.0511)
FDI-Green-NRD		-0.00303		-0.000445
(*Non-green specialised regions*)		(0.00570)		(0.00361)
FDI-Green-NRD		0.0116*		0.0306***
(*Green specialised regions*)		(0.00662)		(0.00899)
FDI-NGreen-RD		-0.0253*		-0.0158
(*Non-green specialised regions*)		(0.0147)		(0.0116)
FDI-NGreen-RD		0.000678		0.0106
(*Green specialised regions*)		(0.0160)		(0.0236)
FDI-NGreen-NRD		-0.000573		-0.000616
(Non-green specialised regions)		(0.00224)		(0.00143)
FDI-NGreen-NRD		-0.00167		-0.00865***
(Green specialised regions)		(0.00196)		(0.00329)

Average marginal effects from probit model (see Table 4). Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Table D2 – Technological relatedness as a moderating factor: persistence vs switch

Dependent variable: RTA in green technology (dummy)	(1) GreenSpec if RTA>1	(2) GreenSpec if RTA>1.5
Relatedness	3.024***	2.407**
(*Non-green specialised regions*)	(0.953)	(0.982)
Relatedness	5.931***	7.485***
(*Green specialised regions*)	(0.519)	(0.635)
FDI-Green-RD	1.132**	1.139***
(*Non-green specialised regions*)	(0.441)	(0.437)
FDI-Green-RD	1.816***	1.502**
(*Green specialised regions*)	(0.527)	(0.733)
FDI-Green-NRD	-0.0277	0.0464
(*Non-green specialised regions*)	(0.0497)	(0.0523)
FDI-Green-NRD	0.0624	-0.0528
(*Green specialised regions*)	(0.0902)	(0.136)
FDI-NGreen-RD	-0.527**	-0.441*
(*Non-green specialised regions*)	(0.208)	(0.265)
FDI-NGreen-RD	-0.165	-1.743***
(*Green specialised regions*)	(0.249)	(0.619)
FDI-NGreen-NRD	0.0137	-0.0633**
(Non-green specialised regions)	(0.0247)	(0.0300)
FDI-NGreen-NRD	0.000933	0.170***
(Green specialised regions)	(0.0258)	(0.0615)
FDI-Green-RD	-12.16***	-9.298**
(Non-green spec regions) x Relatedness	(4.483)	(4.309)
FDI-Green-RD	-14.96***	-11.50*
(Green spec regions) x Relatedness	(4.985)	(6.455)
FDI-Green-NRD	0.307	-0.403
(Non-green spec regions) x Relatedness	(0.496)	(0.485)
FDI-Green-NRD	-0.451	0.947
(Green spec regions) x Relatedness	(0.724)	(1.060)
FDI-NGreen-RD	4.604**	3.270
(Non-green spec regions) x Relatedness	(1.964)	(2.219)
FDI-NGreen-RD	1.499	14.74***
(Green spec regions) x Relatedness	(2.039)	(5.170)
FDI-NGreen-NRD	-0.134	0.599**
(Non-green spec regions) x Relatedness	(0.247)	(0.285)
FDI-NGreen-NRD	-0.0510	-1.701***
(Green spec regions) x Relatedness	(0.252)	(0.542)
Pseudo R sq	0.156	0.175
N	3054	3015

Probit model. Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: country-by-year dummies, GreeSpec pre-sample mean (1991-1994), Relatedness, Region's share of country patents, KETs (lag), log(GDP), GDP growth in 2007-2009 interacted with time dummies, log(pop density), log(R&D per capita) of NUTS2, Share of working age population with tertiary degree of NUTS2, Exposure to env policy (PC#1), Exposure to env policy (PC#2), EPS x Exposure to env policy (PC#1), EPS x Exposure to env policy (PC#2). Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Appendix E – Results for the continuous dependent variable (pooled OLS and fixed effects)

Table E1 – Inward FDIs and green regional technological specialisation – pooled OLS and FE; continuous dependent variable

Dependent variable: RTA in green technology (continuous)	Pooled OLS			FE		
	(1)	(2)	(3)	(4)	(5)	(6)
FDI	0.000441			-0.000189		
	(0.000496)			(0.00109)		
FDI-Green		0.00961			-0.00612	
		(0.00699)			(0.00992)	
FDI-NGreeen		-0.00167			0.00156	
		(0.00155)			(0.00287)	
FDI-Green-RD			0.0444*			0.0412*
			(0.0230)			(0.0235)
FDI-Green-NRD			0.00207			-0.00300
			(0.00273)			(0.00361)
FDI-NGreen-RD			-0.00806			-0.00787
			(0.00526)			(0.00736)
FDI-NGreen-NRD			-0.000448			0.000107
			(0.000709)			(0.00126)
N	3066	3066	3066	3066	3066	3066

Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: country-by-year dummies, GreeSpec pre-sample mean (1991-1994), Relatedness, Region's share of country patents, KETs (lag), log(GDP), GDP growth in 2007-2009 interacted with time dummies, log(pop density), log(R&D per capita) of NUTS2, Share of working age population with tertiary degree of NUTS2, Exposure to env policy (PC#1), Exposure to env policy (PC#2), EPS x Exposure to env policy (PC#1), EPS x Exposure to env policy (PC#2). Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Table E2 – Technological relatedness as a moderating factor – pooled OLS and FE; continuous dependent variable

Dependent variable: RTA in green technology (continuous)	(1) Pooled OLS	(2) FE
Relatedness	4.021***	-0.927
	(1.233)	(1.681)
FDI-Green-RD	1.316***	0.826*
	(0.448)	(0.488)
FDI-Green-NRD	-0.0487	-0.0275
	(0.0331)	(0.0361)
FDI-NGreen-RD	-0.145*	0.0542
	(0.0793)	(0.114)
FDI-NGreen-NRD	0.0130	-0.00240
	(0.0109)	(0.0181)
FDI-Green-RD	-12.48***	-7.488
x Relatedness	(4.396)	(4.769)
FDI-Green-NRD	0.499	0.177
x Relatedness	(0.339)	(0.369)
FDI-NGreen-RD	1.276	-0.561
x Relatedness	(0.819)	(1.206)
FDI-NGreen-NRD	-0.131	0.0393
x Relatedness	(0.122)	(0.198)
N	3066	3066

Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: country-by-year dummies, GreeSpec pre-sample mean (1991-1994), Relatedness, Region's share of country patents, KETs (lag), log(GDP), GDP growth in 2007-2009 interacted with time dummies, log(pop density), log(R&D per capita) of NUTS2, Share of working age population with tertiary degree of NUTS2, Exposure to env policy (PC#1), Exposure to env policy (PC#2), EPS x Exposure to env policy (PC#1), EPS x Exposure to env policy (PC#2). Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Table E3 – Persistence vs switch in the regional green-tech specialization (RQ4) – pooled OLS and FE; continuous dependent variable

Dependent variable: RTA in green technology (continuous)	Pooled OLS (1)	(2)	FE (3)	(4)
FDI-Green	-0.00313		0.0120	
(*Non-green specialised regions*)	(0.00675)		(0.0129)	
FDI-Green	0.0292**		-0.0230*	
(*Green specialised regions*)	(0.0122)		(0.0134)	
FDI-NGreen	-0.000188		-0.000706	
(*Non-green specialised regions*)	(0.00150)		(0.00345)	
FDI-NGreen	-0.00552**		0.00304	
(*Green specialised regions*)	(0.00276)		(0.00361)	
FDI-Green-RD		0.0379		0.115
(*Non-green specialised regions*)		(0.0810)		(0.0893)
FDI-Green-RD		0.0885*		0.0757
(*Green specialised regions*)		(0.0523)		(0.0542)
FDI-Green-NRD		-0.00672		0.00984
(*Non-green specialised regions*)		(0.00810)		(0.0134)
FDI-Green-NRD		0.0254*		-0.0294**
(*Green specialised regions*)		(0.0132)		(0.0147)
FDI-NGreen-RD		-0.0153		0.00464
(*Non-green specialised regions*)		(0.0132)		(0.0147)
FDI-NGreen-RD		-0.0105		-0.0206
(*Green specialised regions*)		(0.0236)		(0.0324)
FDI-NGreen-NRD		0.00158		-0.00127
(Non-green specialised regions)		(0.00246)		(0.00434)
FDI-NGreen-NRD		-0.00474		0.00533
(Green specialised regions)		(0.00313)		(0.00435)
N	3066	3066	3066	3066

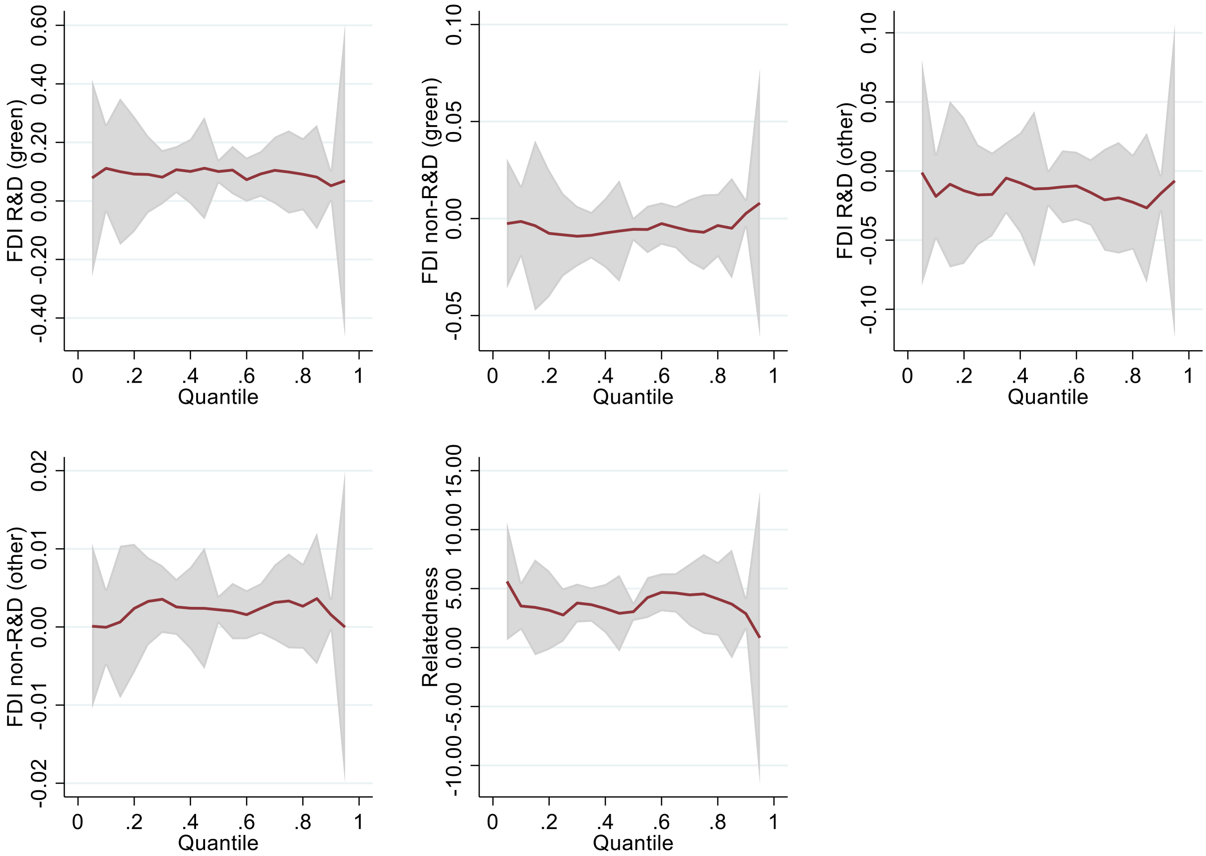
Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: country-by-year dummies, GreeSpec pre-sample mean (1991-1994), Relatedness, Region's share of country patents, KETs (lag), log(GDP), GDP growth in 2007-2009 interacted with time dummies, log(pop density), log(R&D per capita) of NUTS2, Share of working age population with tertiary degree of NUTS2, Exposure to env policy (PC#1), Exposure to env policy (PC#2), EPS x Exposure to env policy (PC#1), EPS x Exposure to env policy (PC#2). Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Table E4 – Technological relatedness as a moderating factor: persistence vs switch – pooled OLS and FE; continuous dependent variable

Dependent variable: RTA in green technology (continuous)	(1) Pooled OLS	(2) FE
Relatedness (*Non-green specialised regions*)	1.990 (1.233)	-0.264 (1.700)
Relatedness (*Green specialised regions*)	4.589*** (0.468)	-2.834*** (0.564)
FDI-Green-RD (*Non-green specialised regions*)	1.592** (0.684)	1.387** (0.670)
FDI-Green-RD (*Green specialised regions*)	0.751 (0.538)	-0.274 (0.583)
FDI-Green-NRD (*Non-green specialised regions*)	-0.0724 (0.0455)	-0.0771* (0.0449)
FDI-Green-NRD (*Green specialised regions*)	0.0188 (0.0611)	0.0752 (0.0624)
FDI-NGreen-RD (*Non-green specialised regions*)	-0.143 (0.132)	-0.0519 (0.123)
FDI-NGreen-RD (*Green specialised regions*)	-0.301** (0.148)	-0.0404 (0.252)
FDI-NGreen-NRD (Non-green specialised regions)	0.00882 (0.0176)	0.00521 (0.0220)
FDI-NGreen-NRD (Green specialised regions)	0.0196 (0.0170)	-0.0112 (0.0242)
FDI-Green-RD (Non-green spec regions) x Relatedness	-15.65** (6.601)	-13.00** (6.422)
FDI-Green-RD (Green spec regions) x Relatedness	-7.074 (5.462)	3.118 (5.935)
FDI-Green-NRD (Non-green spec regions) x Relatedness	0.742 (0.469)	0.754 (0.471)
FDI-Green-NRD (Green spec regions) x Relatedness	-0.0809 (0.572)	-0.778 (0.580)
FDI-NGreen-RD (Non-green spec regions) x Relatedness	1.338 (1.343)	0.494 (1.273)
FDI-NGreen-RD (Green spec regions) x Relatedness	2.581* (1.341)	0.300 (2.378)
FDI-NGreen-NRD (Non-green spec regions) x Relatedness	-0.0693 (0.187)	-0.0444 (0.241)
FDI-NGreen-NRD (Green spec regions) x Relatedness	-0.230 (0.174)	0.123 (0.245)
N	3066	3066

Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: country-by-year dummies, GreeSpec pre-sample mean (1991-1994), Relatedness, Region's share of country patents, KETs (lag), log(GDP), GDP growth in 2007-2009 interacted with time dummies, log(pop density), log(R&D per capita) of NUTS2, Share of working age population with tertiary degree of NUTS2, Exposure to env policy (PC#1), Exposure to env policy (PC#2), EPS x Exposure to env policy (PC#1), EPS x Exposure to env policy (PC#2). Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Figure E1 – Baseline estimation with quantile regression for $GreenRTA_{it}$ (in log)



Appendix F - Heterogeneous effects

Further insights about the relationship between inward FDIs and regional green-tech specialisation can be obtained by distinguishing different kinds of environmental technologies and different types of specialising regions.

As regards the characteristics of green technologies, the literature has increasingly emphasised the differences in their stage of development, detectable by looking at the regional spread (i.e. number of areas specialized in the technology, as a proxy of diffusion) and at the patenting intensity in each green technology field. To account for the these characteristics of green technologies, we followed Perruchas et al. (2020) and Barbieri et al. (2020a) and considered the four stages of the technology lifecycle (TLC)– i.e. 'emergence' (TLC1), 'development' (TLC2), diffusion' (TLC3), and 'maturity' (TLC4) - and re-allocated each 2-digit class of our OECD-ENVTECH taxonomy to one of the four TLC phases.[1] Given the very low number of patents assigned to some stages and regions, in order to preserve the efficiency of our estimates we have grouped together the 'emergence' (TLC1) and 'development' (TLC2) classes, sharing a high geographical concentration, into the group "early stage" green-technologies; similarly, we have assembled the 'diffusion' (TLC3) and 'maturity' (TLC4) classes, characterized by a growing geographical diffusion and standardization, into the group "later stage" green-technologies. We have then used this bipartition to re-estimate, for each of the two groups of green technologies, the parsimonious version of our model that addresses RQ3, without distinguishing between already green-tech specialized and not specialized regions (see Table 3).

Table F1 shows that our main results hold irrespective to the maturity of the considered environmental technologies. Inward FDIs in R&D favour the regional specialisation only when they are green, and they do so for green technologies at both at an early (Column 1) and late (Column 2) stage of the lifecycle. However, important differences emerge by looking at marginal effects in Table F2. In particular, the impact of green FDIs in R&D on regional specialization is almost twice as large for more mature environmental

[1] We consider the 2000 rather than the 2010 definition. Results based on the 2010 definition are qualitatively very similar and remain available upon request.

technologies compared to less mature ones. This suggests that the entry of foreign knowledge in the region can more effectively recombine with local competencies when the properties and the characteristics of the target green technologies are already established and possibly standardised.

Table F1 – Baseline estimation for green technologies at different stages of the technology life-cycle

Dependent variable: RTA in selected technologies (dummy) broken down by technology lifecycle stage	(1) Early stage green-tech (TLC1-2; 2000 definition)	(2) Later stage green-tech (TLC3-4; 2000 definition)
FDI-Green-RD	0.149**	0.213**
	(0.0688)	(0.0930)
FDI-Green-NRD	-0.00475	-0.00814
	(0.0126)	(0.0123)
FDI-NGreen-RD	-0.0590**	-0.0394*
	(0.0293)	(0.0212)
FDI-NGreen-NRD	0.00289	0.00187
	(0.00257)	(0.00293)
Pseudo R sq	0.0872	0.107
N	3006	3041

Probit model. Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: country-by-year dummies, GreeSpec pre-sample mean (1991-1994), Relatedness, Region's share of country patents, KETs (lag), log(GDP), GDP growth in 2007-2009 interacted with time dummies, log(pop density), log(R&D per capita) of NUTS2, Share of working age population with tertiary degree of NUTS2, Exposure to env policy (PC#1), Exposure to env policy (PC#2), EPS x Exposure to env policy (PC#1), EPS x Exposure to env policy (PC#2). Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

Table F2 – Average marginal effects for Table F1

	Early stages (1-2; 2000 definition)	Later stages (3-4; 2000 definition)
FDI-Green-RD	0.0461**	0.0743**
	(0.0212)	(0.0324)
FDI-Green-NRD	-0.00147	-0.00284
	(0.00390)	(0.00427)
FDI-NGreen-RD	-0.0183**	-0.0138*
	(0.00907)	(0.00739)
FDI-NGreen-NRD	0.000894	0.000651
	(0.000795)	(0.00102)

Average marginal effects from probit model (see Table 5). Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

As for the heterogeneity across types of regions, we have focused on four differentiating characteristics that are particularly salient in dealing with regional green technologies: i) the level of economic outcome during the 2008 crisis, as the regions' capacity to benefit from FDIs in reaching a green-tech specialisation could vary with their resilience to this big shock; ii) population density, as the effect of FDIs on green-tech specialisation could be stronger in areas that benefit from larger infrastructures and agglomeration economies (such are metropolitan areas); iii) country-level environmental regulatory stringency (captured by the EPS indicator), as in regions within more stringent countries our focal relationship could find a higher regulatory push; iv) R&D per capita, as the green-tech impact of FDIs could be favoured, if not even conditioned, by a higher level of local inventive activities and absorptive capacity.

Table F3 – Baseline estimation for regions with different characteristics

Dependent variable: RTA in selected technologies (dummy)	(1)	(2)	(3)	(4)
FDI-Green-RD	0.309**	0.0151	0.0937	0.0276
	(0.124)	(0.124)	(0.116)	(0.141)
FDI-Green-NRD	0.00810	0.0100	0.00878	0.00664
	(0.0175)	(0.0209)	(0.0164)	(0.0180)
FDI-NGreen-RD	-0.0159	-0.0779*	-0.0495	-0.0143
	(0.0399)	(0.0462)	(0.0310)	(0.0410)
FDI-NGreen-NRD	-0.00205	0.0145	0.000185	0.00254
	(0.00478)	(0.00932)	(0.00465)	(0.00655)
FDI-Green-RD	-0.240			
x GDP growth 07-09 < median (dummy)	(0.154)			
FDI-Green-NRD	-0.00109			
x GDP growth 07-09 < median (dummy)	(0.0245)			
FDI-NGreen-RD	-0.0795			
x GDP growth 07-09 < median (dummy)	(0.0507)			
FDI-NGreen-NRD	0.00232			
x GDP growth 07-09 < median (dummy)	(0.00688)			
FDI-Green-RD		0.205		
x Pop density > median (dummy)		(0.157)		
FDI-Green-NRD		-0.0143		
x Pop density > median (dummy)		(0.0248)		
FDI-NGreen-RD		-0.0133		
x Pop density > median (dummy)		(0.0543)		
FDI-NGreen-NRD		-0.0107		
x Pop density > median (dummy)		(0.0102)		
FDI-Green-RD			0.0654	
x EPS > median (dummy)			(0.138)	
FDI-Green-NRD			-0.00285	
x EPS > median (dummy)			(0.0214)	
FDI-NGreen-RD			-0.0600	
x EPS > median (dummy)			(0.0484)	
FDI-NGreen-NRD			0.00278	
x EPS > median (dummy)			(0.00525)	
FDI-Green-RD				0.170
x R&D pc > median (dummy)				(0.161)
FDI-Green-NRD				-0.0101
x R&D pc > median (dummy)				(0.0229)
FDI-NGreen-RD				-0.117**
x R&D pc > median (dummy)				(0.0509)
FDI-NGreen-NRD				0.00331
x R&D pc > median (dummy)				(0.00760)

Pseudo R-sq	0.0899	0.0920	0.0880	0.0898
N	3054	3054	3054	3054

Probit model. Observations: NUTS3 regions for three periods (2003-2006; 2007-2010; 2011-2014). Additional variables: country-by-year dummies, GreeSpec pre-sample mean (1991-1994), Relatedness, Region's share of country patents, KETs (lag), log(GDP), GDP growth in 2007-2009 interacted with time dummies, log(pop density), log(R&D per capita) of NUTS2, Share of working age population with tertiary degree of NUTS2, Exposure to env policy (PC#1), Exposure to env policy (PC#2), EPS x Exposure to env policy (PC#1), EPS x Exposure to env policy (PC#2). Standard errors clustered by region in parenthesis. * p<0.1, ** p<0.05, *** p<0.01.

We have then re-estimated the baseline model by building a dummy that captures the regions' position with respect to the median of each of the four variables and by interacting it with our focal FDI regressors. Table F3 reports the results of these estimates and Table F4 the relative marginal effects.

The first column of Table F3 shows that green FDIs in R&D exert a significantly positive effect on green technology specialization only for regions that were not badly hit by the 2008-2009 recession[2]. Furthermore, Table F4 reveals that non-green FDIs in R&D have a negative effect on the same specialisation in the regions that have experienced a large collapse in the aftermath of the same recession. This is quite interesting and might suggest that the local resilience to large economic shocks represents a necessary context condition for green FDIs in R&D to favour the regional specialisation in environmental technologies. Indeed, a large resilience (i.e. a low impact of the recession) seems even capable to neutralize the negative effect that non-green FDIs in R&D otherwise (high impact) exert on the same capacity.

Coming to population density, while the negative effect of non-green FDIs in R&D is somehow ubiquitous (Table F3, column 2), Table F4 shows that the positive effect green FDIs is fully driven by the more populated regions. This is an important result, hinting that foreign green investments in R&D may foster the local development of Greentech specialisation exclusively in the presence of those urbanisation and agglomeration advantages that are present in the more densely populated areas (such as metropolitan areas). The average positive effect we have detected for green FDIs in R&D in Table 3 does also appear mainly driven by regions within relatively more environmentally stringent countries (Table F4), pointing to a wider spectrum of applications of the regulatory-push approach to EIs. Lastly, our focal relationship between green FDIs in R&D and green-tech specialisation appears to be moderated by a high level of R&D

[2] This finding is quite consistent with the descriptive evidence offered in section 3.2.1 on changes in green-tech specialisation of regions in times of crisis

intensity in the specialising regions, suggesting that an appreciable local endowment of innovative knowledge and absorptive capacity is crucial to leverage R&D FDI into fostering regional specialisation in environmental technologies.

Table F4 – Average marginal effects for Table F3

	Crisis impact		Population density		Env policy stringency		R&D intensity	
	Low impact#	High impact##	Low	High	Low	High	Low	High
FDI-Green-RD	0.109**	0.0245	0.00530	0.0752**	0.0332	0.0562*	0.00979	0.0694**
	(0.0433)	(0.0328)	(0.0434)	(0.0317)	(0.0409)	(0.0306)	(0.0501)	(0.0281)
FDI-Green-NRD	0.00285	0.00249	0.00352	-0.00145	0.00311	0.00209	0.00235	-0.00121
	(0.00615)	(0.00623)	(0.00731)	(0.00493)	(0.00583)	(0.00562)	(0.00639)	(0.00540)
FDI-NGreen-RD	-0.00560	-0.0339***	-0.0273*	-0.0312***	-0.0176	-0.0387***	-0.00506	-0.0462***
	(0.0140)	(0.0110)	(0.0162)	(0.00998)	(0.0110)	(0.0132)	(0.0145)	(0.0113)
FDI-NGreen-NRD	-0.000723	0.0000932	0.00508	0.00132	0.0000654	0.00105	0.000899	0.00206
	(0.00168)	(0.00177)	(0.00324)	(0.00145)	(0.00165)	(0.00142)	(0.00232)	(0.00152)

Average marginal effects from probit model (see Table 6). Standard errors clustered by region in parenthesis. * $p<0.1$, ** $p<0.05$, *** $p<0.01$. [#] Above-median GDP growth in 2007-2009; [##] below-median GDP growth in 2007-2009.