Green technologies and smart specialisation strategies:
a European patent-based analysis of the
intertwining of technological relatedness and Key-Enabling-Technologies.

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Abstract

This paper investigates the move of regions towards sustainable growth through their specialisation in new green technologies. In particular, we analyse the role that smart specialisation strategies (S3) can have in this respect by addressing two research questions. First of all, we investigate whether the environmental diversification of regional technologies is, according to the S3 logic, driven by their "relatedness" to existing knowledge of green and non-green nature. Second, we analyse the role of the Key Enabling Technologies (KETs) that S3 policies recommend regions to prioritise, not only in fostering the adoption of environmental technologies, but also in affecting its dependence on the pre-existing knowledge-base. Combining regional patent and economic data for a 34-year panel (1980-2013) of 180 European regions, we find that the relatedness to the existing technological-base of the region actually makes the acquisition of a new green-tech specialisation more probable. This holds true with respect to both the green and non-green extant knowledge, pointing to a regional diversification that also benefits from the "hybridisation" of non-environmental technologies. The latter however requires a higher degree of relatedness than a "pure" green branching process. Regional KETs also help the transition towards sustainable technologies. What is more, they negatively moderate the green impact of the relatedness to pre-existing technologies, of both green and non-green nature, and thus attenuate the boundaries the latter could pose to regions in their environmental specialisation. These results confirm that S3 policies can actually boost the intertwining of a smart and sustainable kind of growth, and that the KETs inclusion within S3 can amplify the virtuous interaction between these two objectives.

Key-words: Smart Specialisation Strategies; Sustainable Growth; Regional branching; KETS

JEL-codes: R11; R58; O31; O33.

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1. Introduction

The smart specialisation concept and its translation into regional research and innovation strategies (RIS3) have been developed within a wide policy context, in which Europe recognises as pivotal the triple objective of a smart, sustainable and inclusive growth (i.e., the Europe 2020 policy framework). RIS3 have actually been recognised relevant for all of these three priorities, and for environmental sustainability in particular. Shifting towards a more resource-efficient and low carbon-economy could arguably be more effective by integrating it within the selective set of priorities of the region. Sustainability achievements could/should be pursued through technological and practice-based innovations, which build on the regional distinctive strengths and on the processes of entrepreneurial discovery germinating from its stakeholders (EC, 2012a). Following this argument, the European Commission (2012b) has recently encouraged regional (and national) policy makers to "connect[…] smart and sustainable growth through smart specialisation" and to accordingly identify context-based opportunities to develop and exploit the potential of green-technologies.

In spite of this policy attention, the research on how smart specialisation strategies (S3) can actually contribute to a green sustainable development at the regional level is still scanty. More in general, very limited is the extent to which environmental issues have entered into regional studies so far. Research agendas for a more encompassing analysis of the locational implications of the green economy are actually still looked for at the intersection between regional studies, economic geography and sustainability transition (Truffer and Coenen, 2012; Gibbs and O'Neill, 2017).

The present paper aims at contributing to fill this gap and investigates the process through which regions move towards sustainable growth by specialising in new green technologies. In particular, we investigate whether two key-pillars of the S3 argument can actually help regions in mastering new technologies for the sake of their green development. Firstly, we look at the S3 "principles of regional embeddedness and relatedness" (EC, 2012a, p. 14) and inspect the extent to which each and every region can "ecologically modernise" its embedded knowledge-base (Gibbs, 2006) by diversifying it in a related way: that is, through a process that economic geography has recently termed "regional branching" (Boschma and Frenken 2011a). In so doing, we build on and extend previous case-based (e.g. Cooke, 2008; 2012) and systematic evidence (Tanner, 2014; van den Berge and Weterings, 2013) on a green kind of regional branching. In particular, we re-examine the process of recombinant innovations on which regional branching draws and disentangle the role of green vs. non-green knowledge in its occurrence. While recognising that new specialisations in environmental technologies could benefit from their relatedness to the existing green knowledge-base of the region, we also retain that the proximity to the non-green one could help regions filter those "standard" technologies, which could be recombined and possibly hybridised into new eco-specialisations (Zeppini and van den Bergh, 2011).

Secondly, we concentrate on the Key Enabling Technologies (KETs) that the European Commission has claimed to be part of S3 (EC, 2012a, p. 86) and investigate their regional environmental impact in two respects. On the one hand, we focus on the potential of industry "modernisation" that the EC has recognised to KETs. KETs are actually six special kinds of technologies – i.e. industrial biotechnology, nanotechnology, micro-and nano-electronics, photonics, advanced materials, and advanced manufacturing technologies – that are crucial for the upgrading of existing regional technologies in the direction of "grand societal challenges", among which climate change and environmental protection figure out as prominent (EC, 2012c, 2012d). On the other hand, we reconsider in the environmental domain the impact that, given their horizontal nature and transformative potential, KETs have been found to have on the unfolding of regional branching in general (Montresor and Quatraro, 2017). In particular, we address the extent to which the combinatory properties of KETs can attenuate the role of relatedness in driving green branching, by making it less binding for the acquisition of new specialisations in the environmental area.

The two questions that we address increase the engagement of regional studies in the analysis of environmental sustainability and have important policy implications in terms of S3. First of all, the analysis of green vs. non-green relatedness is able to inform policy makers about the opportunity of targeting environmental sustainability as a priority in S3, even in presence of a (strongly) weakly developed green (non-green) knowledge-base. Second, the "moderating" role of KETs could persuade policy makers to integrate them in their S3, also as a potential lever to overcome the adverse implications of green branching: regions starting with a weakly developed (green or non-green) knowledge-base, would be somehow condemned to accept a lower capacity of developing new eco-technologies. By making their pre-existing competencies less relevant for future branching, KETs could actually attenuate this sort of "lock-iness" and increase the extent to which regions can specialise into new sustainable technologies.

In order to test our arguments about green technologies and S3, we carry out an empirical application on 180 NUTS2 regions of 15 EU countries over the period 1981-2013. The application is based on a novel dataset, which combines the OECD RegPat database (March 2017) and the Cambridge Econometrics Region Database. Furthermore, in order to identify green technologies we make use of the OECD Env-Tech classification (OECD, 2015), based on the International Patent Classification (IPC) and the Collaborative Patent Classification (CPC).

Results reveal that the relatedness to the existing technological-base of the region actually makes the acquisition of a new green-tech specialisation more probable. This holds true with respect to both green and non-green extant knowledge, pointing to a regional diversification that possibly benefits also from the "hybridisation" of existing non-environmental technologies. On the other hand, the latter apparently requires a higher degree of relatedness than a "pure" green branching process. As expected, regional KETs also help the acquisition of green technologies. Furthermore, they negatively moderate the green impact of the relatedness to pre-existing technologies and thus attenuate the boundaries the latter could pose to regions in their environmental specialisation.

The rest of the paper is organised as follows. Section 2 illustrates the background literature of the paper. Section 3 presents the empirical application, the data and the econometric strategy through which it was performed. Section 4 discusses the main results. Section 5 concludes and illustrates the policy implications.

2. Background literature

As Gibbs and O'Neill (2017) have recently recognised, in spite of the increasing concern for the environmental impact of economic development at the local level, the green economy has been addressed by regional studies to a is still limited extent. Their review of the literature does not find substantial additions to the picture that Truffer and Coenen (2012) had already delineated five years before.[1] The most interesting insights about how economies can move towards a greener pattern of growth have been obtained by sustainability transition research (for a recent overview, see Markard et al., 2012). Its focus on the formation of "socio-technical systems" (Rip and Kemp, 1998), which express the co-evolution of technological and socio-organisational elements towards sustainable development trajectories, has actually help disentangle the complexity that characterises the achievement of environmental sustainability. Within this framework, the so-called Multilevel Perspective (MLP) of eco-innovation (Geels, 2005; Smith, 2003) has recently recognised that the "niches" from which sustainable "socio-technical regimes" evolve often have, at least initially, a local-scale dimension (Coenen et al., 2010). Accordingly, regions and cities have been identified as key-contexts where the seeds of sustainability transitions can germinate, to be eventually scaled-up at a wider geographical level (Badinger et al., 2016).

In spite of some recent efforts to substantiate these conceptual insights and to map their evidence on the territory (on this, see the cases illustrated by Gibbs and O'Neill (2017)), the research on sustainability transition remains however largely a-spatial. Socio-technical systems are mainly depicted as "footloose cognitive and institutional structures" (Truffer and Coenen, 2012, p. 6). In particular, transition is mainly addressed at the national level, at most by comparing its unfolding across different countries (e.g. Smith et al., 2010; Raven and Geels, 2010). The locational dimension of sustainability is obviously more present in regional studies, where the complexity of phenomenon has however been "reduced" by focusing on some specific dimensions of it, which Truffer and Coenen (2012) have identified in: the "ecological modernisation" that technologies can bring into regional production and consumption patterns (Gibbs, 2006); the "industrial ecosystems" that can be realised on the territory by designing material, water and energy exchanges at the local level (Chertow, 2008); the "policy-led initiatives" (e.g. governance experimentation and public-private coordination) through which "sustainable regions" can be planned (Haughton and Morgan, 2008). In their review, Truffer and Coenen (2012) also address the way environmental sustainability has been investigated by economic geography (p. 8) and identify a promising line of research for its analysis in the studies on "regional branching", pointing to the diversification regions undertake relatedly to their existing activities (Asheim et al., 2011). Such a research line would actually be capable to account, at the local level, for the "vertical (e.g. multi-level governance; supply chains)" and "lateral (e.g. path-dependence; inter-industry relatedness and knowledge spillovers) dimensions" that characterise the sustainability transition (Cooke, 2011, p. 107). Indeed, in the majority of the cases, regions come to master new environmental activities by recombining their existing knowledge-base,

[1] A previous state-of-the-art paper had been written by Haughton and Morgan (2008), as the editorial of a special issue of Regional Studies on "Sustainable regions".

both of green and non-green nature, creating diffused cases of crossover between them: the combination of knowledge from agro-engineering and renewable energy, or from automotive engineering and agro-food, represent two notable examples.

The previous streams of literature – sustainability transition, regional studies, and economic geography – represent three different perspectives of green regional sustainable growth that complement each other and between which the most recent studies are trying to find a suitable overlapping (Truffer and Coenen, 2012; Boschma et al., 2017). Following these last contributions, we investigate the process through which regions move towards sustainable growth by specialising in new but related green technologies. As we said in the introduction, such an analysis is capable to shed light on the extent to which the same transition can actually be helped by S3 and S3 policies.

First of all, following the ecological modernisation approach in regional studies, we start by recognising that "green technologies" – that is, technologies that find application in the attempt of mitigating, if not even reversing, the environmental impact of human development – are of upmost importance for a sustainable kind of growth at the local level. As the literature on the so-called "eco-innovations" has shown from a different but related perspective, through a proper combination of policy-regulations, competences, and market drivers, the development of new green technologies can simultaneously contribute to coupling and decoupling growth, to new knowledge development, and from environmental degradation, respectively (Fussler and James, 1996; Horbach and Rennings, 2012; Kemp and Pontoglio, 2007; Ghisetti and Pontoni, 2015). While already pervasive at the micro and the macro-level, the connection between green technologies and sustainability has started to be investigate only recently at the regional one (Truffer and Coenen, 2012). Still, increasing evidence is amounting about the relevance of geography and spatial elements for green technologies and eco-innovations (e.g. Turner, 2006; Munday and Roberts, 2006; Cainelli et al., 2012; Ghisetti and Quatraro, 2013; Horbach, 2014; Antonioli et al., 2016; Leoncini et al., 2016).

Second, we draw on economic geography and on its recent combination with transition studies (Boschma et al., 2017) to focus on the regional acquisition of new green technologies through processes of regional branching. At the outset, we stick to the economic geography idea that, thanks to the occurrence of "recombinant innovations" (Castaldi et al., 2015), mastering new technologies in a region can be in general facilitated by the presence of technologies in the existing industrial structure, which are cognitively related to them: an hypothesis that has found ample empirical confirmation (e.g. Koegler et al., 2013; Rigby, 2013; Boschma et al., 2014; Tanner, 2014; Colombelli et al., 2014; Boschma et al., 2015; Castaldi et al., 2015; Montresor and Quatraro, 2017). Combining economic geography with transition studies, we then maintain that regional sustainability is also driven by a process of regional technological branching, and that new environmental "niches" of a sustainable socio-technical system develop by exploiting their "relatedness" to existing technological regimes. Using the recent diversification taxonomy proposed by Boschma et al. (2017), we expect that new green technology specialisations are mainly acquired through an "exaptation" kind of regional diversification, rather than by "replication", "saltation", or even "transplantation" (p. 38).

This extension of the regional branching thesis to the green realm has both theoretical and empirical support. Potentially, regions can move towards environmental sustainability following heterogeneous patterns, which could even substantially depart from their existing knowledge base and industrial structure. As there is no "one-size-fits-all" recipe for doing it, some regions could opt for a "radical" approach, and embark on brand new eco-trajectories of growth somehow from scratch (e.g. the production of electric cars in absence of a consolidated experience in the automobile sector), by approaching new environmental niches in an unrelated way (in Boschma et al. (2017) words, by "saltation"). Some regions could even go for a "transformative" approach, which entails a paradigmatic shift towards newly sustainable patterns of production and consumption (like the adoption of "circular-economy" models), in which unrelated diversification even leads to new environmental regimes (i.e., by "transplantation"). From a locational perspective, in these cases the geography of sustainability is quite unpredictable and accordingly hard to be encapsulated into the regional branching framework. On the other hand, while possible, these regional environmental approaches are hard to implement in practice and arguably infrequent (Simmie, 2012). The technologies for "greening" the regional economies in many cases are at an early stage of their life-cycle (Consoli et al., 2016) and their knowledge-base is often quite complex to master, entailing a lot of uncertainty in undertaking them from scratch (Braungart et al., 2007). For these reasons, radical approaches to regional sustainability can be deemed exceptional and only suitable to those (few) regions that have: on the one hand, the capacity of creating a niche environment outside their existing technological base (Simmie, 2012); on the other hand, the combination of social capital, institutional and normative set-ups to accompany the costs and perils of the relative transformation (EC, 2012a, p. 20). More often, the regional approach to the development of new eco-technologies is "incremental" and, according to the regional branching story, actually occurs by recombining existing technologies related to them and by exploiting the occurrence of local spillovers also with respect to green innovations (Antonioli et al., 2016).

The fact that regions actually master new specializations in eco-technologies through branching processes has been initially pointed out by some detailed case studies (see, for example, Cooke, 2008; 2012; Morgan, 2008; Donald, 2008; Fornhal et al., 2011). Only recently, these insights have been confirmed by more systematic analyses, which mainly make use of patent data. Looking at the development of the fuel-cell industry in European regions, Tanner (2014) actually finds that the higher the number of fuel-cell related technological fields present in a given region, the more likely a region is to branch into fuel-cell technology. In a wider study of a number of new technological developments in climate change and alternative energy sources, van den Berge and Weterings (2013) find that European regions having already developed a revealed comparative advantage (RCA) in fields related to a specific eco-technology, are more likely to develop a RCA in that eco-technology too.

All in all, the branching interpretation of the regional acquisition of new environmental technologies find substantial elements of support. On the other hand, its analysis would benefit from the investigation of two further aspects, which have been so far relatively neglected. First of all, the process of knowledge recombination that leads to green branching draws on a regional knowledge-base, which is made up of both green and non-green technologies and whose balance is of course region-specific. In principle, one could claim that the capacity of entering into the green realm is helped the more (if not even exclusively), the closer the new technology is to the pre-existing green knowledge of the region. Indeed, an initial environmental experience can be expected to generate a path-dependent development process, in which previous eco-innovations provide knowledge that can serve as an input for further eco-innovations, and in which regions "learn to learn" (Stiglitz, 1987) in the environmental domain. In other words, the regional "basket" of green ideas and practices the region already controls, represents an important inducement mechanism for the acquisition of new green technologies.

Following the previous argument, relying on the relatedness to the previous non-green knowledge of the region should be expected to make its green branching less feasible, if not even hamper it. However, this is so only in principle. Once applied to non-green (if not even dirty) technologies, the path-dependence argument would in fact diminish the region propensity to gain new green specialisations, as hysteresis could possibly occur in the development of non-green ones too. On the other hand, the region could exploit the chance to make non-environmental technologies functional to its environmental transition by exploiting the possibility to combine them into new hybrid solutions, like the hybrid car – combining an internal combustion engine with an electric propulsion one – or photovoltaic films – combining thin layer technologies with solar cells (see Zeppini and van den Bergh (2011) for a more detailed illustration). Such hybridisation is of course far from being automatic and does not emerge for the simple fact of combining any green with any non-green kind of knowledge. On the contrary, it arguably requires a certain knowledge overlapping between green and non-green technologies, that is, a degree of cognitive complementarity between them, which their relatedness could account for. In brief, the relatedness to pre-existing non-green technologies could also drive green branching and to a possibly different (arguably inferior) extent than that to green ones. Given the region-specific balance between the two kinds of knowledge, and the different strategies regions could follow in exploiting them for the sake of diversification, this is an aspect that requires close consideration.

The second aspect that could enrich the analysis of green regional branching is the consideration of the role that special kinds of technologies have on its occurrence, such as for those the European Commission has called "Key Enabling Technologies" (KETs). As illustrated by the feasibility study that has led to their identification (EC, 2012c), these are six technologies – i.e., industrial biotechnology, nanotechnology, micro- and nanoelectronics, photonics, advanced materials, and advanced manufacturing technologies — that act as building blocks for a wide array of products and industrial processes in today's economies. Like their more standard GPT counter-part, KETs have two special properties (Bresnahan, 2010), which make them pivotal in the functioning of the recombinant innovations at the basis of regional branching. First of all, by their horizontal nature, KETs move the region's technological frontier ahead and thus makes its existing technological paradigm less limiting of the recombination of its existing ideas (Olson and Frey, 2002). Second, through their typical co-invention/application pattern, KETs can extend their extant applicative path to a new inventive one, bringing out truly innovative re-combinations of existing ideas (Frenken et al, 2012). In so doing, they can allow regions to obtain new re-combinations that are less technologically closer to the extant ones.

Both these KETs effects have been recently found at work in the empirical analysis of the role of KETs in the regional branching of Europe in the last two decades (Montresor and Quatraro, 2017). On the other hand, the role of KETs with respect to green branching has not been addressed yet and, given the different mechanisms behind the role of KETs with respect to pre-existing green and non-green knowledge (cumulativeness vs. hybridization), it requires close consideration. As for the former, our expectation is that KETs could enable regions to explore more distantly from their existing green-knowledge base, by combining the shift they entail in the relative frontier with the opportunity of new invention/application combinations: as a result, KETs should make the relatedness to existing environmental knowledge less binding for the acquisition of new eco-specialisations. As for non-green knowledge, the capacity of KETs to facilitate the recombination of the technologies to which they apply, can be expected to favour the development of the kind of hybrid (green with non-green) solutions to which we have referred to above, by creating and thus make the relative relatedness also less binding.

In conclusion, it seems to us to have enough argument to suggest that the analysis of regional sustainable development should integrate the functioning of regional branching with: on the one hand, the distinction between the green and non-green knowledge-base of the regon, on the other hand, the role of KETs. This is what we will do in the empirical application that follows.

3. Empirical application

3.1. Data

The empirical application of the paper is based on a regional dataset of 15 EU countries (the EU 28, minus Croatia) over the period 1981-2010. The dataset was obtained by merging georeferenced patent micro-data at the NUTS2 level, drawn from the OECD Reg Pat dataset (March 2017), with those collected at the same territorial level by the European Regional Database (Cambridge Econometrics).[2].

Following the extant literature, the region's capacity to branch into a new green technology is here investigated by looking at its new technological specialisations in the green domain (see the next Section). In turn, this is measured through the number of patent applications registered within the regional boundaries in environmentally coded IPC classes. As is well-known, patents suffer from important limitations as a technology proxy, also at the regional level, in particular due to their bias towards a Science, Technology and Innovation (STI) mode (Acs and Audretsch, 1989; Acs et al., 2002). Similarly, the distinction between green and non-green patents has been carried out by referring to several patent classifications, each of which has its

[2] http://www.camecon.com/SubNational/SubNationalEurope/RegionalDatabase.aspx

own limits in terms of missing technologies (on this, see Costantini et al. (2013)). Among these classifications, the very last version of the OECD “Environmental Technologies” indicators, *ENV-TECH*, is the most comprehensive taxonomy (Haščič and Migotto, 2015) and we accordingly chose to rely on it for our empirical analysis.

Patent data have been also used to identify KETs knowledge and investigate their role in green regional branching. In particular, we looked at the number of regional patent applications in KETs-mapped IPC classes, using the EC Feasibility Study on KETs (see Vezzani et al., 2014). Finally, patent data are also the ingredients to measure the technological relatedness between the new green and the existing technologies, along with other technological determinants of regional branching (see the next Section).

As far as the European Regional Database (ERD) is concerned, this has been the reference to proxy for other “economic” determinants of (green) regional branching and to obtain some regional controls necessary for its analysis.

3.2 Variables

The dependent variable of our analysis is the acquisition by region *i* of a new green technological specialisation *s* at time *t*: that is, a specialisation in any technology *s* belonging to the green classification, which the region did not have at time $t - k$. If we identify a green technological specialisation with a standard patent-based indicator of Revealed Technological Advantages (RTA_GREEN_{ist}) *a là* Balassa, its newness can be characterised by a dichotomic variable, $NewRTA\_GREEN_{ist}$, taking value 1 if such an advantage is new and 0 otherwise:

$$NewRTA\_GREEN_{ist} = 1, if\ RTA\_GREEN_{ist} > 1\ and\ 0 < RTA\_GREEN_{ist-k} < 1$$

$$NewRTA\_GREEN_{ist} = 0, otherwise \qquad (1)$$

where:

$$RTA_{ist} = \frac{PAT_{ist}}{\sum_{i=1}^{n} PAT_{ist}} \Bigg/ \frac{\sum_{s=1}^{m} PAT_{ist}}{\sum_{i=1}^{n}\sum_{s=1}^{m} PAT_{ist}} \qquad (2)$$

with PAT_{ist} equal to the number of patent applications registered at time *t* within region *i* (out of *n*) with respect to technology *s* (out of *m*), and with $GREEN\_RTA_{ist} = RTA_{ist}$ for each and every patent-class *s* belonging to the green classification: that is, for s ∈ *ENV_TECH.*[3]

As far as the lag for the emergence of a new classification is concerned, following the extant literature we posed it equal to 5 years (that is, $k = 5$) and run some robustness check about this choice, obtaining confirmative results.[4] Furthermore, in order to get rid of the inevitable impact that the inherent volatility of patent statistics has on the calculus of RTA, a five-year moving average was used in the construction of the dependent variable and of the other patent-related ones.

The set of regressors that we use to investigate the dynamics of $NewRTA\_GREEN_{ist}$ over time is consistent with the process of regional branching we intend to test in environmental terms. First of all, we built up a variable that accounts for the relatedness of each newly acquired technology *s* to the existing ones of the region. In particular, drawing on previous studies (Colombelli et al., 2014), we have extended Hidalgo et al.'s (2007) representation of the product space of a country to the technology space of a region. By relying on patent data, for each and every new technology, *s*, we have thus worked out the density ($Dens_{ist}$) of the proximity indicators, φ_{szt}, between it and all of the technologies *z* the region was specialised at time $t - k$ (with *k* still equal to 5) as follows:

$$Dens_{ist} = \frac{\sum_{s \neq z} \varphi_{szt} x_{ist-5}}{\sum_{s \neq z} \varphi_{szt}} \qquad (3)$$

where $x_{ist-5} = 1$ if $RTA_{ist} > 1$ (and 0 otherwise) and where:

$$\varphi_{szt} = min\{P(RTA_{ist}|RTA_{izt}, P(RTA_{izt}|RTA_{ist})\} \qquad (4)$$

with $P(RTA_{ist}|RTA_{izt}) = \frac{P(RTA_{ist} \cap RTA_{izt})}{P(RTA_{izt})}$.

As long as a technology *s* is included in the OECD Env Tech classification, $Dens_{ist}$ represents the relatedness between that new green technology and the existing technological specializations of the region, as a proxy of its technological knowledge-base (see Colombelli et al. (2014) for details). As we have argued in the previous

[3] As is well known, according to Equation (2), such an indicator would reveal a specialisation when it is greater than 1, and the absence of it when its value is in-between 0 and 1. Let us notice that, although such an indicator should be normalised when using is actual value, its normalisation is not necessary when it is just used to build up the dummy variable $NewRTA\_GREEN_{ist}$. Let us also notice that, although with a different meaning, $NewRTA\_GREEN_{ist}$ would take value 0 also when a green-tech specialisation already exists in *t-k* and is confirmed by the region at time *t*.

[4] These are available from the authors upon request.

Section, such a knowledge-base is in turned made up of both green and non-green pre-existing technologies, with different branching mechanisms and potential. In order to disentangle this aspect, we have broken down the density into two indicators, which proxy the relatedness of each new (green) technology to the green (*Dens_Green*$_{ist}$) and non-green (*Dens_Non-Green*$_{ist}$) knowledge-base of the region, respectively, as follows:

$$Dens\_GREEN_{ist} = \frac{\sum_{s \neq z}(\varphi_{szt} x_{ist-5}) * Green_z}{\sum_{s \neq z} \varphi_{szt}} \qquad (5)$$

$$Dens\_Non - GREEN_{ist} = \frac{\sum_{s \neq z}(\varphi_{szt} x_{ist-5}) * Non - Green_z}{\sum_{s \neq z} \varphi_{szt}} \qquad (6)$$

where $Green_z$ = 1 if z ∈ Env_Tech, and 0 otherwise (Equation 5), and $Non\text{-}Green_z$ = 1 if z ∉ Env_Tech, and 0 otherwise (Equation 6).

In order to test our arguments about the role of KETs in regional branching, we have referred again to the notion of RTA and first counted the number of cases in which region *i* had obtained a technological specialization in a KETs-related IPC class, irrespectively of the specific KETs in which this had occurred. Calculating the five-year moving average of this aggregate variable, for the same reasons as before, and referring to its 1-year time lag (and still with robustness checks for other lags) for detecting its pre-existence, we have thus built up a variable, *KETs_RTA*$_{it-1}$, which proxies the generic KETs knowledge of *i*. While sharing common properties – that is, a horizontal nature and a transformative potential similar to that recognised to standard General Purpose Technologies (GPT) (Bresnahan, 2010) – the six KETs have quite important distinguishing features, for example, in terms of stage of their life cycle and industries/countries of main diffusion. In particular, it could be claimed that the last two of them – i.e. advanced materials, and advanced manufacturing technologies – have wider GPT properties than the previous four. In order to control for the possible repercussion of this heterogeneity in terms of green branching, the *KETs_RTA*$_{it-1}$ indicator has been replicated for each and every individual KETs by referring to the relative IPC classes (see again Vezzani et al., 2014).

The list of independent variables is completed by three kinds of controls. First of all, drawing on the eco-innovation literature (see Ghisetti and Pontoni, 2015), we have controlled for the role of regulation in pushing/pulling the development of green technologies by referring to the OECD environmental policy stringency (*EPS*$_{ct-1}$) indicator at the country-level (*c*) (Botta and Kozluk, 2014). In particular, we have followed Albrizio et al. (2017) and constructed a three-year moving average for the change in EPS, that is, an unweighted average of the first, second and third lag of the change in EPS.[5] A second control has been introduced to account for the fact that the classification set out by the OECD to identify green technologies is a finite repertoire. This implies that there is a sort of ceiling for the number of green specializations that a region can developed, which is defined by the number of technologies included in the classification. For this reason, saturation dynamics might be observed, according to which the higher the number of green specializations already observed in a place, the lower the opportunities for that area to enter a new green specialization. We have controlled for this confounding effect by including the 5-years moving average cumulated number of green specializations observed in region i at time $t-1$ (RTA_GREEN_{it-1}). Finally, we have inserted a third control for regional size heterogeneity by referring to the 1 year lagged value of the 5-years moving average of regional gross value added (GVA_{it-1}).

Table 1 summarizes the variables used in the study, how they were defined, and the data sources upon which they built.

Insert Table 1 about here

Table 2 reports the main descriptive statistics of these variables, while Table 3 shows the pairwise correlations among all of them.

Insert Tables 2 and 3 about here

3.3. Econometric strategy

The model that we used to test our research arguments is implicitly defined as follows:

$$NewRTA\_GREEN_{ist} = f(Dens_{ist}, KETs\_RTA_{it-1}, Dens_{ist} \times KETs\_RTA_{it-1},$$

$$EPS_{ct-1}, RTA\_GREEN_{it-1}, GVA_{it-1}, dtime, dregion, \epsilon) \qquad (7)$$

where in addition to the previously defined variables, *dtime* and *dregion* are year and regional dummies, respectively, and ε is an error term with standard properties.

In addition to the role of $KETs\_RTA_{it}$ in affecting the scope for green regional branching ($NewRTA\_GREEN_{ist}$), the focal feature of this model is the presence of an interaction term between KETs and the technological

[5] The EPS indicator is a composite one that bridges market based (taxes, trading schemes, feed-in tariffs and deposit refund measures) and non-market based (Standards and R&D subsidies) environmental policies, reporting their stringency values (in a 0-6 scale) in terms of the explicit or implicit price of the produced environmental damage mainly in the field of air and climate policies. Its reliability is shown by its high correlation with alternative policy indicators, like the World Economic Forum's Executive Opinion Survey on the perception of environmental policy stringency and the CLIMI Climate Laws, Institutions and Measures Index produced by the EBRD.

relatedness of the new technologies to the pre-existing ones, $Dens_{ist}$. Consistently with our theoretical arguments in Section 2, our expectation is that not only do KETs positively affect $NewRTA\_GREEN_{ist}$, but they also negatively moderate the positive effect that, according to the branching hypothesis, $Dens_{ist}$ is expected to have on $NewRTA\_GREEN_{ist}$.

In order to test for our argument about the different branching role of green vs. non-green knowledge, model (7) has been also estimated by substituting $Dens\_GREEN_{ist}$ and $Dens\_Non\text{-}GREEN_{ist}$ for $Dens_{ist}$, and the marginal effects of the two have been compared. The same sequence of specifications has been followed to inspect the moderating role of KETs, which is expected to be negative with respect to both kinds of knowledge.

As far as the other variables are concerned, in view of the inducement hypothesis spelt out by Johnstone et al. (2012), as well as of the regulatory push/pull character of eco-innovation (Rennings, 2000), EPS_{ct-1} is expected to yield a positive effect on the development of new green specializations. Finally, given its control for possible saturation dynamics, the coefficient of RTA_GREEN_{it-1} is expected to be negative.

The estimation of model (7) is not straightforward, as it is characterized by a dichotomous-dependent variable. Previous empirical applications have opted to estimate it using a linear probability model (LPM) (Boschma et al., 2013; Colombelli et al., 2014): a special case of a binomial regression, in which the probability of observing 0 or 1 is modelled in such a way that ordinary least squares (OLS) can be used to estimate the parameters. However, in our analysis we decided to implement a logit estimation of our empirical models. This choice has the advantage to be consistent with the binary nature of the dependent variable, hence allowing for bounded predicted probabilities. The LPM instead does not ensure that predicted probabilities are in the interval [0,1]. Moreover, it violates the normality of the error term and homoscedasticity assumption, which are crucial to provide reliable estimations and standard errors. Finally, the logit model allows for the identification of marginal effects and hence for quantifying the impact of our independent variables on the probability that a region develops a new green technological specialization.

4. Results

The first set of results of our analysis (Tables 4 and 5) refer to the estimate of model (7) when KETs are considered in aggregate terms, without distinguishing their six typologies. To start with, Table 4 reports the results of the logit estimations carried out by looking at the "general" relatedness of newly acquired green technologies to the entire basket of pre-existing regional specialisations ($Dens_{ist}$). Both here and elsewhere we show marginal effects instead of coefficients. The baseline specification (Column (1)) shows that, according to the regional branching argument, the relatedness to the pre-existing knowledge-base of the region makes the acquisition of a new green technology more probable. Having controlled for other structural determinants – EPS_{ct-1} and GVA_{it-1} have the expected signs, though the latter is not significant – our hypothesis of a green kind of regional branching appears confirmed.

Insert Table 4 about here

The baseline results are confirmed when the history of previous green specialisations (*RTA_GREEN_{it-1}*) is also controlled for, though this is not significant at the outset (Column (2)). The latter become significant (although only weakly) and with an expected negative sign – actually showing evidence of a saturation dynamics in acquiring new green technologies – when the role of KETs is plugged into the model (Columns 3 and 4). As expected, mastering KETs knowledge seems to enable regions to embark in modernisation processes of their technologies, which also entail a shift towards further sustainability: *$KETS\_RTA_{it-1}$* is significant and positive in both specifications (4) and (5). What is more, the marginal effect of the interaction between *$KETS\_RTA_{it-1}$* and *$Dens_{ist}$* is significant too and negative. Coherently with previous studies (Montresor and Quatraro, 2017), while enhancing the region's capacity to build on exploration dynamics and develop new green specializations, local KETs attenuate the importance of path-dependence. Not only do KETs provide regions willing to approach a path of sustainable development with an extra technology-leverage to do so, in addition to that of their pre-existing green experience. But they also make the latter less binding for a new green specialisation to occur, thus reducing the possible disadvantages of less environmentally experienced regions.

Table 4 provides results that are immediately comparable with the previous literature about regional branching, which, as we said, finds confirmation in the green domain. As we argued in Section 2, additional insights about its holding can be found by disentangling the extent to which the regional capacity to branch in environmental terms is driven by the relatedness to pre-existing green rather than non-green knowledge. In this last respect, Table 5 includes among the regressors both the focal densities at stake, *$Dens\_GREEN_{ist}$* and *$Dens\_Non\text{-}GREEN_{ist}$*, and compare their marginal effects.

Insert Table 5 about here

First of all, let us notice that the innovative recombination of the extant green knowledge of the region does actually favour the acquisition of new one: *$Dens\_GREEN_{ist}$* is positive and significant across all of the specifications. As expected, the acquisition of a new eco-specialisation is driven by dynamic cumulativenss and learning processes with respect to it. On the other hand, Table 5 shows that *$Dens\_Non\text{-}GREEN_{ist}$* does also exert a positive and significant marginal effect on *$NewRTA\_GREEN_{ist}$*. This result points to an additional driver of green branching, which passes through the recombination of related pre-existing non-green knowledge into new and possibly hybrid eco-solutions. Indeed, as we said, while diffused in practice – one just need to think of electric cars - such a hybridisation is far from being automatic and does not emerge for the simple fact of combining any green with any non-green kind of knowledge. On the contrary, it arguably requires a certain knowledge overlapping between green and non-green technologies, that is, a degree of cognitive complementarity between them, which their relatedness could account for. This last result about the driving role that the relatedness to pre-existing non-green technologies has for the acquisition of new green ones appears quite robust and apparently not affected by the non-negligible correlation that, while not creating multi-collinearity problems (as reported, the VIF tests exclude their presence), Table 3 shows between *$Dens\_GREEN_{ist}$* and *$Dens\_Non\text{-}GREEN_{ist}$*. Tables A1 and A2 in the Appendix actually shows that both kinds of density are significant and with a positive sign also when they are individually and exclusively plugged in the regression. Furthermore, quite interestingly, when the endowment of environmental knowledge of the region is exclusively retained (Table A1), the acquisition of a new eco-specialisation is exclusively driven by dynamic irreversibility and learning processes with respect to it. Conversely, when $Dens\_Non\text{-}GREEN_{ist}$ is considered in isolation (Table A2), the inserted controls regain their significance and expected sign (apart from GVA).

As far as the comparative marginal effects of the two densities are concerned, Table 5 shows that, with the exception of one specification only (including the interaction between KETs and the green density (Column (5)), $Dens\_Non\text{-}GREEN_{ist}$ appears to exert a larger impact on $NewRTA\_GREEN_{its}$ than $Dens\_GREEN_{ist}$. Not only can regions branch into a new green technology by recombining their green as well as their non-green knowledge-base. The relatedness to the latter has also a larger green branching effect than the relatedness to the former, suggesting that the pre-existing non-environmental knowledge of the region requires a higher degree of cognitive proximity to the new eco-solution it can contribute to develop, possibly through a hybridisation process. In other words, while green regional branching is also driven by related non-green knowledge, the relative relatedness is more binding than the relatedness to pre-existing green knowledge.

In the light of this last result, it turns out particular important the significant negative interaction that KETs reveal in Table 5, not only with respect to $Dens\_GREEN_{ist}$, but also with respect to $Dens\_Non\text{-}GREEN_{ist}$. It appears that KETs could help the environmental regional transition in two respects. Not only do they allow regions to explore more distant eco-technologies from their available ones. But they also help to relax the stronger complementarities that new green technologies are found to require with respect to existing "standard" ones.

By referring to KETs in general and aggregated terms, the previous set of estimates investigate the extent to which green regional branching is affected by their common "horizontal" and "transformative" features. On the other hand, as we said, the six KETs are arguably different among them, and this could differentiate their impact on the issue at stake. In particular, one might suspect that the results we have obtained about their favouring new green regional specialisations are limited to those KETs of the six, which according to their identification (see EC, 2012d, 2012e) are closer to an environmental application, that is, advanced materials, and advanced manufacturing technologies. In order to investigate this issue, Table 6 reports the focal estimations of our benchmark model, that is with $Dens_{ist}$ in aggregate terms, for each and every of the six KETs taken individually.

Insert Table 6 about here

The results actually show that, unlike with respect to regional branching in general (Montresor and Quatraro, 2017), the six KETs do not play all a significant role in the environmental domain. As we could have expected, the results of the general analysis are confirmed by the most GPT kind of KETs, that is, Advanced technologies (KETs6) and Advanced materials (KETs5), which both favour the acquisition of a new green technology (though the latter with a weak significance) and attenuate the relevance of the density to the pre-existing knowledge for that to happen (the relative moderation is significant and negative). The same twofold KETs pattern is confirmed only by Photonics (KETs4), which thus deserves special attention in the analysis of the green regional transition. A "narrower" green branching impact is shared by Biotech (KETs1) and Nano-electronics (KETs3), which both "simply" attenuate the green impact of relatedness (showing a significant and negative interaction with it), but without revealing a direct effect on the acquisition of new eco-solutions. Finally, and quite unexpectedly, no effect on the issue at stake is found for Nanotechnologies (KETs2). The previous set of results is generally confirmed when, as we have done for KETs in general, $Dens_{ist}$ is substituted for $Dens\_GREEN_{ist}$ and $Dens\_Non\text{-}GREEN_{ist}$ (Tables A3). In particular the direct effects of KETs holds only for a subset of typologies i.e. Advanced Technologies (KETs6) and Photonics (KETs4), while the direct effect is not significant as far as the other classes of KETs. The effects of both denisities are positive and significant across all of the specifications. The larger magnitude of the marginal effect of $Dens\_Non\text{-}GREEN_{ist}$ as compared to $Dens\_GREEN_{ist}$ is also confirmed in this set of estimations. Also, the coefficients of the interactions between the individual KETs and the two densities are negative in all models, and significant in all models but two. In particular, for what concerns KETs3 and KETs2, Nano-electronics and Nanotechnologies respectively, only the interaction with $Dens\_GREEN_{ist}$ shows a significant coefficient.

All in all, it seems that the green kind of branching that we are investigating is mainly driven by the general properties that KETs share, and could thus possibly be helped by a wide and comprehensive approach to their development in the region. When their individual and specific features are disentangled, their green role becomes more puzzled and points to heterogeneous green branching effects. Accordingly, at least for the sake of this objective, a more selected and specific approach to the development of individual KETs should demand a careful inspection of their specific environmental applications: an inspection that we postpone to our future research agenda.

5. Conclusions

Environmental sustainability is an imperative that regions are increasingly more compelled to address in their growth strategies for the future. The pressures posed by climate change, environmental risks, energy and resource scarcity - among the others - are actually manifest also and above all at the local level, where they interact with the density of population, migration flows and production activities. On the other hand, regions and cities are often the ideal settings from which the "niches" of a transition towards sustainability can start, by incubating the combination of those technological and socio-organisational dimensions that drive the green-evolution of socio-technical systems (Gibbs and O'Neill, 2017).

In spite of their twofold environmental role, in posing both green pressures and green opportunities, regions have been only scantly addressed so far in their move towards sustainability. The theoretical interpretations are still fluid across different disciplines – mainly, regional studies, economic geography and transition research - and in search of fruitful combinations (Truffer and Coenen, 2012; Boschma et al., 2017).

Furthermore, the empirical analysis of regional green development is still mainly case-based and systematic investigations hesitate to take off (e.g. van den Berge and Weterings, 2014; Tanner, 2014). As a result of that, policy implications about how to foster the regional move towards the green economy are also rather diffused and in need of a stronger research support. An apparent example is the recent claim by the European Commission to "connect smart and sustainable growth through smart specialisation" (EC, 2012b), whose recommendation is generically based on the opportunity of inserting sustainability among the priorities S3 should pursue by exploiting local processes of entrepreneurial discovery.

The present paper has contributed to fill his gap by addressing the role that S3 and S3 policy could have in fostering the regional acquisition of new green technologies. In particular, by combining the three research perspectives to the issue, we have argued that such a role could be theoretically founded by addressing the occurrence of green regional branching (the S3 principle of relatedness) and by investigating the effect that "special" technologies, like the six S3-related KETs, exert on its unfolding.

The empirical application we have run with respect to 180 European NUTS2 regions over the period 1981-2013 has confirmed these theoretical arguments and augmented them with some new insights. On the one hand, regions do show an incremental and path-dependent approach to environmental sustainability, as the relatedness - or cognitive proximity - to the pre-existing knowledge-base of the region plays a pivotal role in its acquisition of new green technologies. In policy terms, been actually anchored to the principles of "embeddedness and relatedness", environmental sustainability could and should actually be plugged in regional S3, leaving regions the scope to approach it by context-specific environmental recombinations of existing activities. Quite interestingly, such an environmental recombination appears to draw on both the extant green and non-green knowledge of the region, possibly in the form of technology hybridisation processes. This would suggest that environmental sustainability can be accessible through S3 also to those regions, whose knowledge-base is not intensively or predominantly green and rather "normally" marked by context-specific balances between green and non-green knowledge. On the other hand, in order to gain new eco-solutions for the region, these need to be cognitively closer to the extant non-environmental knowledge than to the environmental one: accordingly, those regions in which the knowledge balance is predominantly non-green could be more bounded in their green branching than those with a dominated green balance. In brief, while "non-green" regions could recombine their technologies in environmental terms as well as "green regions", the latter can do it in a more explorative way.

The previous result connects to the role that KETs, at least in general, have been found to have in attenuating the green impact of relatedness. Not only do KETs contribute to the ecological modernisation of the region. But they also increase the scope of recombining its existing into new green knowledge, thus mitigating the path-dependence on both the green and non-green knowledge of the region. In brief, KETs seem to allow regions more explorative processes of both "pure" green branching and of green "hybridisation". This last result has an important policy implication. Indeed, inserting KETs in S3, as the recent developments of S3 policy are suggesting, could be justified by an extra enabling role that KETs could play: that is, of a potential lever to overcome the adverse implications of green branching, in terms of path-dependence if not even of lock-iness.

As usual, the paper is not free from limitations and requires extensions to which further research will be dedicated. First of all, other forms of relatedness than the technological one will have to be considered in the acquisition of new green specialisations, starting from the geographical one and from the spatial spillovers the development of KETs could be exposed. Second, the role of KETs in green regional branching could be further sophisticated by looking at their role in possibly allowing regions to shift from non-green to green technologies.

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Table 1 – Variables definitions and sources

Variables	*Definition*	*Source*
$NewRTA\_GREEN_{ist}$	Dummy variable identifying the emergence of a new technological specialization in green technology (GREEN) *s*, which were observed at time *t* but not at time *t-5*, in region *i*	Our own elaborations on OECD RegPat Database (March 2017).
$Dens_{ist}$	Density of the proximity linkages that each technology observed at time *t* in region *i* reveals with respect to all of the technologies observed in the same region at time *t-5*.	Our own elaborations on OECD RegPat Database (March 2017).
$Dens\_Green_{ist}$	Density of the proximity linkages that each technology s observed at time *t* in region *i* reveals with respect to all of the green technologies observed in the same region at time *t-5*.	Our own elaborations on OECD RegPat Database (March 2017).
$Dens\_Non\text{-}Green_{ist}$	Density of the proximity linkages that each technology s observed at time *t* in region *i* reveals with respect to all of the non-green technologies observed in the same region at time *t-5*.	Our own elaborations on OECD RegPat Database (March 2017).
$KETS\_RTA_{it-1}$	Number of KETs in which region *i* is technologically specialised at time *t-1*. Five years moving average. Inverse sine transformation.	Our own elaborations on OECD RegPat Database (March 2017); EC (2011).
RTA_GREEN_{it-1}	Number of green technologies in which region *i* is technologically specialised at time *t-1*. Five years moving average. Inverse sine transformation.	Our own elaborations on OECD RegPat Database (March 2017); EC (2011).
GVA_{it-1}	Logarithm of the gross value added of region *i* at time *t-1*. Five years moving average. Inverse sine transformation.	Cambridge Econometrics (December 2014)
EPS_{ct-1}	Enviromental Policy Stringency Index (at country level, c). Three years moving average. Inverse sine transformation.	OECD

Table 2 - Descriptive statistics

Variable	*N*	*mean*	*min*	*max*	*Sd*	*skewness*	*kurtosis*
$NewRTA\_GREEN_{ist}$	3807540	.0023782	0	1	.0487085	20.43264	418.4927
$Dens_{ist}$	3484980	.0917493	0	1	.106473	2.059554	10.69289
$Dens_{ist}$ * $KETs\_RTA_{it-1}$	2766240	.5828862	0	8.0984	.7288734	2.120754	10.21095
$Dens\_GREEN_{ist}$	3430980	.0346722	0	1	.0678281	4.892996	49.64276
$Dens\_GREEN_{ist}$ * $KETS\_RTA_{it-1}$	2727000	.2267634	0	8.077385	.4415875	4.537843	43.04377
$Dens\_Non\text{-}GREEN_{ist}$	3484260	.1076151	0	3	.1276859	1.98779	10.56174
$Dens\_Non\text{-}GREEN_{ist}$ * $KETS\_RTA_{it-1}$	2766060	.6862116	0	18.32509	.8677196	1.976818	9.147019
$KETS\_RTA_{it-1}$	2999880	4.593198	0	8.0984	2.096817	-.7484459	2.671219
RTA_GREEN_{it-1}	3346020	2.505476	0	6.100324	1.651267	-.1037297	1.96481
GVA_{it-1}	2810785	10.75996	0	13.72151	1.113021	-1.737476	16.38797
EPS_{ct-1}	2294780	1.379836	.4874144	2.178767	.3440857	-.358243	2.365765

Table 3 - Pairwise correlation matrix

	Variables	1	2	3	4	5	6	7	8	9	10	11
1	$NewRTA\_GREEN_{ist}$	1.0000										
2	$Dens_{ist}$	0.0631*	1.0000									
3	$Dens_{ist}$ * $KETs\_RTA_{it-1}$	0.0610*	0.9822*	1.0000								
4	$Dens\_GREEN_{ist}$	0.0325*	0.4797*	0.4817*	1.0000							
5	$Dens\_GREEN_{ist}$ * $KETS\_RTA_{it-1}$	0.0337*	0.5183*	0.5376*	0.9779*	1.0000						
6	$Dens\_Non\text{-}GREEN_{ist}$	0.0628*	0.9568*	0.9290*	0.4333*	0.4683*	1.0000					
7	$Dens\_Non\text{-}GREEN_{ist}$ * $KETS\_RTA_{it-1}$	0.0606*	0.9421*	0.9489*	0.4429*	0.4933*	0.9844*	1.0000				
8	$KETS\_RTA_{it-1}$	0.0342*	0.6175*	0.6339*	0.3771*	0.4123*	0.6021*	0.6205*	1.0000			
9	RTA_GREEN_{it-1}	0.0409*	0.7128*	0.7269*	0.4626*	0.4993*	0.6876*	0.7020*	0.8465*	1.0000		
10	GVA_{it-1}	0.0306*	0.5917*	0.6045*	0.3467*	0.3821*	0.5600*	0.5726*	0.7092*	0.7299*	1.0000	
11	EPS_{ct-1}	0.0073*	0.1589*	0.1861*	0.0926*	0.1174*	0.1712*	0.1999*	0.2475*	0.2381*	0.1714*	1.0000

* VIF-tests exclude multicollinearity even in presence of significant correlations.

Table 4 – *NewRTA-GREEN$_{ist}$*: overall relatedness and KETs in general

	(1)	(2)	(3)	(4)
$Dens_{ist}$	0.0135^{***}	0.0135^{***}	0.0136^{***}	0.0223^{***}
	(0.0005)	(0.0005)	(0.0005)	(0.0023)
$KETs\_RTA_{it-1}$			0.0009^{***}	0.0010^{***}
			(0.0003)	(0.0003)
*$Dens_{ist}$ * $KETs\_RTA_{it-1}$*				-0.0014^{***}
				(0.0004)
EPS_{ct-1}	0.0008^{**}	0.0008^{**}	0.0008^{*}	0.0008^{*}
	(0.0004)	(0.0004)	(0.0004)	(0.0004)
GVA_{it-1}	0.0013	0.0014	0.0012	0.0012
	(0.0010)	(0.0010)	(0.0012)	(0.0012)
RTA_GREEN_{it-1}		-0.0001	-0.0004^{*}	-0.0004^{*}
		(0.0002)	(0.0002)	(0.0002)
N	1739273	1739273	1648288	1648288

Marginal effects; Region clustered standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5 – *NewRTA_GREEN$_{ist}$*: relatedness to green and non-green technologies and KETs in general

	(1)	(2)	(3)	(5)	(4)
Dens_GREEN$_{ist}$	0.0029***	0.0029***	0.0030***	0.0135***	0.0030***
	(0.0005)	(0.0005)	(0.0005)	(0.0026)	(0.0004)
Dens_Non_GREEN$_{ist}$	0.0125***	0.0125***	0.0125***	0.0125***	0.0189***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0026)
*Dens_GREEN$_{ist}$ * KETs_RTA$_{it-1}$*				-0.0016***	
				(0.0004)	
*Dens_Non-GREEN$_{ist}$ * KETs_RTA$_{it-1}$*					-0.0010**
					(0.0004)
EPS$_{ct-1}$	0.0008**	0.0009**	0.0009**	0.0009**	0.0008*
	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)
GVA$_{it-1}$	0.0010	0.0012	0.0010	0.0010	0.0009
	(0.0010)	(0.0010)	(0.0012)	(0.0012)	(0.0012)
RTA_GREEN$_{it-1}$		-0.0001	-0.0004*	-0.0004*	-0.0004*
		(0.0002)	(0.0002)	(0.0002)	(0.0002)
N	1716818	1716818	1626918	1626918	1626918

Table 6 – *NewRTA_GREEN*$_{ist}$: relatedness and individual KETS

	(1)	(2)	(3)	(4)	(5)	(6)
$Dens_{ist}$	0.0177***	0.0141***	0.0168***	0.0180***	0.0178***	0.0219***
	(0.0015)	(0.0006)	(0.0013)	(0.0011)	(0.0014)	(0.0018)
$KETs1\_RTA_{it-1}$	0.0002					
	(0.0002)					
$Dens_{ist}$ * $KETs1\_RTA_{it-1}$	-0.0010**					
	(0.0004)					
$KETs2\_RTA_{it-1}$		0.0001				
		(0.0002)				
$Dens_{ist}$ * $KETs2\_RTA_{it-1}$		-0.0008				
		(0.0005)				
$KETs3\_RTA_{it-1}$			0.0002			
			(0.0002)			
$Dens_{ist}$ * $KETs3\_RTA_{it-1}$			-0.0009**			
			(0.0003)			
$KETs4\_RTA_{it-1}$				0.0004**		
				(0.0002)		
$Dens_{ist}$ * $KETs4\_RTA_{it-1}$				-0.0012***		
				(0.0003)		
$KETs5\_RTA_{it-1}$					0.0004*	
					(0.0002)	
$Dens_{ist}$ * $KETs5\_RTA_{it-1}$					-0.0008***	
					(0.0003)	
$KETs6\_RTA_{it-1}$						0.0007***
						(0.0002)
$Dens_{ist}$ * $KETs6\_RTA_{it-i}$						-0.0016***
						(0.0004)
N	1648288	1648288	1648288	1648288	1648288	1648288

Marginal effects; Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

KETs1: Biotech; KETs2: Nanotech; KETs3: Nano-electronics; KETs4: Photonics; KETs5: Advanced materials; KETs6: Advanced technologies.

Appendix

Table A1 – *$NewRTA\_GREEN_{ist}$*: relatedness to green technologies and KETs in general

	(1)	(2)	(3)	(4)
$Dens\_GREEN_{ist}$	0.0040***	0.0040***	0.0040***	0.0125***
	(0.0004)	(0.0004)	(0.0004)	(0.0029)
$KETs\_RTA_{it-1}$			0.0012***	0.0012***
			(0.0003)	(0.0003)
*$Dens\_GREEN_{ist}$ * $KETs\_RTA_{it-1}$*				-0.0013***
				(0.0004)
EPS_{ct-1}	0.0005	0.0005	0.0006	0.0006
	(0.0004)	(0.0004)	(0.0004)	(0.0004)
GVA_{it-1}	0.0012	0.0011	0.0006	0.0006
	(0.0010)	(0.0010)	(0.0011)	(0.0011)
RTA_GREEN_{it-1}		0.0001	-0.0003	-0.0002
		(0.0002)	(0.0002)	(0.0002)
N	1716966	1716966	1627066	1627066

Marginal effects; Region clustered standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A2 – *NewRTA_GREEN$_{ist}$*: relatedness to non-green technologies and KETs in general

	(1)	(2)	(3)	(4)
Dens_Non-GREEN$_{ist}$	0.0116***	0.0116***	0.0116***	0.0164***
	(0.0004)	(0.0004)	(0.0004)	(0.0022)
KETs_RTA$_{it-1}$			0.0010***	0.0010***
			(0.0003)	(0.0003)
*Dens_Non-GREEN$_{ist}$ * KETs_RTA$_{it-1}$*				-0.0008**
				(0.0004)
EPS$_{ct-1}$	0.0009**	0.0009**	0.0009**	0.0009*
	(0.0004)	(0.0004)	(0.0005)	(0.0005)
GVA$_{it-1}$	0.0013	0.0014	0.0011	0.0010
	(0.0010)	(0.0010)	(0.0012)	(0.0012)
RTA_GREEN$_{it-1}$		-0.0001	-0.0004*	-0.0004*
		(0.0002)	(0.0002)	(0.0002)
N	1739125	1739125	1648140	1648140

Marginal effects; Region clustered standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A3 – $NewRTA\_GREEN_{ist}$: relatedness to green and non-green knowledge and individual KETs

	(1)	(2)	(3)	(4)	(5)	(6)
$Dens\_GREEN_{ist}$	0.0070^{***}	0.0044^{***}	0.0068^{***}	0.0075^{***}	0.0075^{***}	0.0120^{***}
	(0.0017)	(0.0006)	(0.0012)	(0.0012)	(0.0016)	(0.0020)
$Dens\_Non\_GREEN_{ist}$	0.0151^{***}	0.0125^{***}	0.0139^{***}	0.0150^{***}	0.0163^{***}	0.0166^{***}
	(0.0016)	(0.0006)	(0.0014)	(0.0012)	(0.0015)	(0.0019)
$KETs1\_RTA_{it-1}$	0.0001					
	(0.0002)					
$Dens\_GREEN_{ist}$ * $KETs1\_RTA_{it-1}$	-0.0009^{**}					
	(0.0004)					
$Dens\_\_Non\_GREEN_{ist}$ * $KETs1\_RTA_{it-1}$	-0.0006^{*}					
	(0.0004)					
$KETs2\_RTA_{it-1}$		0.0001				
		(0.0002)				
$Dens\_GREEN_{ist}$ * $KETs2\_RTA_{it-1}$		-0.0021^{***}				
		(0.0005)				
$Dens\_\_Non\_GREEN_{ist}$ * $KETs2\_RTA_{it-1}$		-0.0001				
		(0.0005)				
$KETs3\_RTA_{it-1}$			0.0000			
			(0.0002)			
$Dens\_GREEN_{ist}$ * $KETs3\_RTA_{it-1}$			-0.0010^{***}			
			(0.0003)			
$Dens\_\_Non\_GREEN_{ist}$ * $KETs3\_RTA_{it-1}$			-0.0004			
			(0.0003)			
$KETs4\_RTA_{it-1}$				0.0004^{***}		
				(0.0002)		
$Dens\_GREEN_{ist}$ * $KETs4\_RTA_{it-1}$				-0.0012^{***}		
				(0.0003)		
$Dens\_\_Non\_GREEN_{ist}$ * $KETs4\_RTA_{it-1}$				-0.0007^{**}		
				(0.0003)		

	(1)	(2)	(3)	(4)	(5)	(6)
KETs5_RTA $_{it-1}$					0.0003	
					(0.0002)	
Dens_GREEN$_{ist}$ * *KETs5_RTA* $_{it-1}$					-0.0009***	
					(0.0003)	
Dens__Non_GREEN$_{ist}$ * *KETs5_RTA* $_{it-1}$					-0.0008**	
					(0.0003)	
KETs6_RTA $_{it-1}$						0.0006**
						(0.0003)
Dens_GREEN$_{ist}$ * *KETs6_RTA* $_{it-1}$						-0.0017***
						(0.0004)
Dens__Non_GREEN$_{ist}$ * *KETs6_RTA* $_{it-1}$						-0.0008**
						(0.0004)
N	1626918	1626918	1626918	1626918	1626918	1626918

Marginal effects; Region clustered standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$