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

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Abstract

The paper investigates the process through which regions get specialised in green technologies for a sustainable kind of growth. In particular, it addresses the extent at which the acquisition of new green knowledge is driven by its technological relatedness to pre-existing one, and the role of Key-Enabling-Technologies (KETS) in making such a relatedness less binding for regional green specialisation. By extending recent research on green regional branching, we argue that the regional approach to environmental sustainability is expectedly gradual and path-dependent. We maintain that general-purpose-technologies like KETS could provide regions with a higher capacity to recombine their existing knowledge for entering into the green realm, thus making their eventual lack of green experience less hampering. Combining regional patent and economic data for a 30-year panel (1980-2010) of 27 European countries, we find that pre-existing green knowledge makes the acquisition of a new green-tech specialisation more probable, and that the same occurs for their cognitive relatedness. KETS also drive this process and attenuate the driving role of technological relatedness. Results support the recent EC recommendation to use Smart Specialisation Strategies in "Connecting Smart and Sustainable Growth", but also suggest to put KETS into the regional policy toolbox for that to happen.

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

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

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1 Introduction

The importance of green technologies for a sustainable kind of growth is part of the research and of policy agenda since long. In particular, the bulk of scientific work and policy initiatives that, at least since the late '90s, have been cumulating on the so-called "eco-innovations" has widely shown that, through a proper policy-regulation and competence setting, 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, at the regional one, the connection between (green-) technologies and sustainability has been recognised only recently, and mainly on a policy ground. As local authorities are marked by a greater "proximity" to the emergence of environmental problems and by a higher control of some innovation policy instruments, which can serve to both growth and sustainability, regions have been argued and found to act more effectively on both levels than their national counterparts (Cooke, 2011). On this ground, EU policy makers have recently assigned the task of connecting smart and sustainable growth to a regional policy concept, like that of smart specialisation strategies (S3) in the use of funds for research and innovation, that is RIS3 (EC, 2012a).

In spite of this policy attention, the research on the mechanisms through which regions come to specialise in green technologies is still scanty. Indeed, while a massive literature exists on regions as *loci* of a variety of innovation spaces (e.g. innovation systems, industrial clusters, districts, incubators, technology parks and the like), the relevance of geography and spatial elements for eco-innovations and sustainability is at a still incipient stage (e.g. Cainelli et al., 2012; Ghisetti and Quatraro, 2013; Antonioli et al., 2016; Leoncini et al., 2016). At present, the most relevant insights on this issue come from some recent attempts at extending to the green realm the logic of regional branching (Boschma and Frenken 2011a), according to which, given the incremental nature of regional learning, the regions' capacity of developing new eco-technologies is dependent on their relatedness to their past knowledge accumulation. Building up and extending previous case studies (e.g. Cooke, 2008; 2012), some first systematic evidence of this kind of "green-branching" has been actually found with respect to European regions (van den Berge and Weterings, 2013).

While for sure important, the role of relatedness in regional eco-technological development is however only part of the story. Another important element that affects the unfolding of regional branching is missing from this analysis and should be transposed to the green realm too: the role of technologies with a general-purpose nature (GPT), like the ones recently identified by the European Commission as Key Enabling Technologies (KETS) (EC, 2009; 2011; 2012b; 2012c; 2012d). As recently shown by Montresor and Quatraro (2017), KETS enter frontally in regional branching (Colombelli et al., 2014; Castaldi et al., 2015) with a twofold role, which the empirical evidence robustly confirms: they boost regional branching itself and, above all, they attenuate the effect that regional branching ascribes to technological relatedness, giving regions more scope for technological diversification. As it is general, this twofold KETS role can be in principle extended also to green branching. Accordingly, it first requires to be considered in order to have a more complete picture of the connection between green technologies and specialisation. Second, the consideration of KETS is urged by the adverse implication of green branching, in that regions starting with a weakly developed green knowledge-base would be condemned to accept a lower capacity of developing new eco-technologies. By making their pre-existing competencies less binding for future branching, KETS knowledge could actually attenuate this sort of "lock-iness" and increases the extent to which regions can specialise into new sustainable technologies even when they have a poor endowment of green knowledge.

This paper aims to analyse to what extent the interplay of regional branching and KETS can help regions in connecting smart and sustainable growth. By adapting the extant literature on regional branching and technological relatedness, we examine whether the probability that a region enters into a new eco-technological field is affected, not only by its relatedness to its existing knowledge base, but also by the regional availability of KETS knowledge, and by its eventual moderation of the effect of technological relatedness on the same probability.

In order to test our arguments, we carry out an empirical application on 312 NUTS2 regions of 28 EU countries (excluding only Croatia from the 28 of the EU due to data constraints) over the period 1981-2010. The application is based on a novel dataset, which combines: the OECD RegPat database (February 2015), and the Cambridge Econometrics Region Database. Furthermore, we make use of the WIPO Green Inventory and the OECD Env Tech classification to tag green technologies. Results suggest that, while there is confirming evidence of green regional branching, all of the six KETS identified by the European policy makers – industrial biotechnology, nanotechnology, micro- and nanoelectronics, photonics, advanced materials, and advanced manufacturing technologies – actually "enable" regions to increase their portfolio of new and related green technologies over time. What is more, all of the six KETS negatively moderate the role of technological relatedness for regional specialization into new green fields. The general role that KETS have in allowing regions to undertake more recombinant innovations, which can be more distant from their existing knowledge base, thus also applies to the green realm: drawing on KETS, sustainability becomes apparently more accessible than what smartness would allow for.

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

The regional acquisition of green technologies can be investigated through a "green" extension of the regional branching thesis (Tanner, 2014). According to the technological declination of this thesis, on which we focus in the paper, mastering new technologies in a region can be generally facilitated by the presence of technologies in the existing industrial structure that are cognitively related to them. From a conceptual point of view, this phenomenon can be accounted by Schumpeter's seminal insight of newly recombining existing ideas and by its recent reformulation in terms of "recombinant innovations" (Castaldi et al., 2015). In brief, the local "variety" of regions in terms of technologies fuels the cross-fertilisation of ideas and the generation of knowledge spillovers, which can feed the innovative process at the local level. However, it is the "relatedness" degree of these heterogeneous activities, expressed by the commonalities in their knowledge base, which makes it easier to innovate by recombining this variety at the regional level. From an empirical point of view, this theoretical argument has found ample confirmation in a number of studies that, mainly by making use of bibliometric and patent data, have found that the so-called "related variety", or "relatedness", plays a crucial role in accounting for the dynamics of scientific knowledge and technological innovations in local areas (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).

In the absence of previous studies, extending the case of regional branching to the green realm is not that immediate, but it can be based on both theoretical and empirical arguments. Potentially, regions can move towards environmental sustainability following heterogeneous patterns, which could even substantially depart from their existing knowledge base and industrial structure (CII-ITC, 2010; EC, 2012a). 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 from scratch (e.g. the production of electric cars in absence of a consolidated experience in the automobile sector). 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). From a locational perspective, in these cases the geography of sustainability is of course 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 (Braungart et al., 2007). Accordingly, a progressively more radical "design rationale" in dealing with the environmental impact of regional activities, by adopting eco-innovations that go beyond "component additions", and rather target "sub-system" or even "system changes", is increasingly more risky, potentially irreversible and accompanied by substantial switching costs (Carrillo-Hermosilla et al., 2010). For these reasons, the 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 eco-technologies through branching processes has been initially pointed out by some notable, detailed case studies, like those by Cooke (2008; 2012): for example, on the branching of agro-food, ICT and biotechnology into a new clean-tech industry in Northern and Southern California, and on the branching of the mining equipment and agro-food Welsh clusters, into the development of photovoltaic and biofuel technologies. Only recently, these insights have been confirmed by more systematic studies, 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.

While already supportive of a green kind of regional branching, these studies are still at an initial stage and require to be extended in at least two directions. From an empirical point of view, in order to make the green branching argument robust, there is the need of further extending the spectrum of eco-technologies to which its inner mechanisms can be proved to apply. From a conceptual point of view, the extension should be completed by recognising the green relevance of the other mechanism that interplays with regional branching in driving regional diversification: the role of GPT and of their recent re-classification into KETS (EC, 2012b).

This latter mechanism has been hitherto neglected in the extant analysis of regional branching, and only recently recovered in investigating the dynamics of technological knowledge undertaken by European regions (Montresor and Quatraro, 2017). In brief, GPT have two special properties (Bresnahan, 2010), which make them pivotal in the functioning of the recombinant innovation theories at the basis of regional branching. First of all, by their horizontal nature, GPT move the general technological frontier of the region ahead and thus attenuate the limits posed by the ruling technological paradigm to the re-combinatory process of its existing ideas (Olson and Frey, 2002). In brief, GPT knowledge could increase the regions' capacity to acquire a certain new technology by branching. Second, through their typical co-invention/application pattern, GPT can link their extant applicative path to a new inventive one, yielding re-combinations that a simple branching would not have made possible (Frenken et al, 2012). In so doing, GPT allow regions to obtain new re-combinations that are less technologically closer to the extant ones.

Both the previous GPT effects have been found at work in the empirical analysis of the role of KETS in the regional branching that European regions have undergone at both the extensive – number of new technological specialisations – and the intensive margin – acquisition of specific new technologies – in the last decades (Montresor and Quatraro, 2017). The endowment of KETS knowledge revealed by the European regions' patent activity in the correspondent fields, has turned out to be a significant explanatory variable of their new technological specialisations, as well as a significantly negative – that is, attenuating – moderating variable of the impact exerted on the same specialisations by their related variety to the pre-existing regional technologies.

Given the general nature of this analysis, the hypothesis that KETS could play a similar role with respect to green branching, that is, for the acquisition of new eco-technologies, appears to us plausible to assume and, as we said, necessary to test in order to complete its analysis. On the other hand, there are also some specific arguments, which make us expect that KETS could interplay with green regional branching. From a conceptual point of view, the theories of recombinant innovations on which KETS insist, and through which they exert their branching effects, have been shown to be of upmost importance also and above all with respect to environmental innovations. In particular, those recombination processes that KETS have been argued to expand have been shown to be pivotal in unlocking an economy from its dirty technologies and in allowing it to move towards clean technologies (Zeppini and van den Bergh, 2011). From an empirical point of view, in a recent analysis of the emergence of the offshore wind energy industry in northern Germany (Fornahl et al., 2012), it has been shown that the regional branching of a new eco-technology could be compatible even with a "distant" regional knowledge-base, but providing some other basic and more general locational conditions for their development are present. The study at hand refers to elements like the access to infrastructure, positive market developments, and national and regional industrial policies. In brief, to a set of "horizontal" factors to the economic structure of a region, to which GPT like KETS can arguably be extended.

In conclusion, it seems to us to have enough argument to suggest that a consistent analysis of the region's capacity to enter into the green realm should integrate the functioning of regional branching with the role of GPT. This is what we will do in the empirical application that follows, where the role of GPT will be investigated by looking at KETS: as we said, a new generation of six GPT - industrial biotechnology, nanotechnology, micro- and nanoelectronics, photonics, advanced materials, and advanced manufacturing technologies - acting as building-blocks of a wide array of products and industrial processes in today's economies (EC, 2011). Of course, while sharing the GPT properties that we have identified, the six technologies are inherently diverse, for example, in terms of stage of their life cycle, industries/countries of main diffusion and, in particular, cognitive proximity to the eco-technologies to which they could apply: an element that we will therefore carefully considered in the empirical application of the next section.

3 Empirical application

3.1 Data

The empirical application of the paper is based on a regional dataset of 27 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 (July 2014), with those of the European Regional Database maintained by Cambridge Econometrics[1] at the same territorial level of analysis.

Following the extant literature, patent data were first of all used to proxy the region's capacity to branch into a new green technology by looking at its technological specialisations (see the next Section). Using a

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

"technology diffusion approach" (EC, 2011, pag. 21), patent data were also used to identify the presence of KETS knowledge in the regions 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 EC Feasibility Study on KETS (see Vezzani et al., 2014). Finally, patent data were also used to measure the technological relatedness between the new green and the existing technologies, and other technological determinants of regional branching (see the next Section).

Technological classes of patent applications were also used to discriminate between patents in environmental (related) technologies, green technologies (*GREEN*) hereafter, and patents in technology fields, which are not related to environmental improvements. Several international classifications have been developed to make this discrimination feasible. Each classification has its own limits in terms of missing technologies, as discussed in Costantini et al. (2013). In order to check for the robustness of our results and to mitigate potential biases, we chose to run estimations by merging the very last version of the OECD "Environmental Technologies" indicators ENV-TECH (Haščič and Migotto, 2015) with the previously established (and much narrower) WIPO IPC codes of the Green Inventory (WIPO, 2012) .

The European Regional Database (ERD) was the reference to proxy for other "economic" determinants of (green) regional branching and to obtain some regional controls necessary for its analysis. Because they are absent from this database, data on regional R&D were taken from EUROSTAT regional statistics and, given the much lower number of observations, were used limitedly in some specifications of the empirical analysis.

3.2 Variables

Given our interest for the regional capacity to gain experience in the environmental realm, the focal dependent variable is region *i*'s new acquisition of a green technological specialisation *s* at time *t*: that is, a green specialisation in *t*, the region did not have at time *t – k*: with a lag that we pose equal to 5 years, by running some robustness check about this choice.

If we identify a green technological specialisation with a standard patent-based indicator of revealed technological advantages (*RTA*), *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:

$$\begin{aligned} &NewRTA\_GREEN_{ist} = 1, \text{ if } GREEN\_RTA_{ist} > 1 \text{ and } 0 < GREEN\_RTA_{ist-k} < 1 \\ &NewRTA\_GREEN_{ist} = 0, \text{ otherwise} \end{aligned} \quad (1)$$

where:

$$RTA_{is} = \frac{PAT_{is} \Big/ \sum_{i=1}^{n} PAT_{is}}{\sum_{s=1}^{m} PAT_{is} \Big/ \sum_{i=1}^{n} \sum_{s=1}^{m} PAT_{is}} \tag{2}$$

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 the environmental realm. First of all, we build up a variable that accounts for the relatedness of each newly acquired green technology to the existing ones of the region. In particular, drawing on previous studies (Colombelli et al., 2014), we extend 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 green technology, we work out the density ($Dens_{ist}$) of the proximity indicators between it and all of the technologies the region was specialised at time $t - k$ (with k still equal to 5, to start with) as follows:

$$Dens_{ist} = \frac{\sum_{s \neq z} \varphi_{szt-1} NewRTA\_GREEN_{ist}}{\sum_{s \neq z} \varphi_{szt-1}} \tag{3}$$

where:

$$\varphi_{szt} = \min\left\{ P(RTA_{st} | RTA_{zt}), P(RTA_{z} | RTA_{s}) \right\} \tag{4}$$

$$P(RTA_{st} | RTA_{zt}) = \frac{P(RTA_{st} \cap RTA_{zt})}{P(RTA_{zt})}$$

$Dens_{ist}$ is thus a proxy for the technological relatedness between the new green and the existing technologies of the region (see Colombelli et al. (2014) for details).

A process of green regional branching would be suggested by a positive correlation between $Dens_{ist}$ and our dependent variable. Consistently with the incremental kind of learning that regional branching assumes, we also expect a significantly positive explanatory role of previous regional experience in green technologies, which we can capture by counting, out of the list of the relevant patent codes, the number of revealed technological advantages region i had acquired in green fields before t, RTA_GREEN_{it-k}: once again, with a lag of 5 years, subject to robustness checks. To be sure, this previous green experience could be also expected to affect the extent at which regions are "bounded" by the reladetness to it, in acquiring new one: for example, a sufficiently large experience of environmental technologies could allow regions to get more distant, and possibly larger, new green specialisations. In order to control for this effect, we also plug in the regression the interaction between $Dens_{ist}$ and RTA_GREEN_{it-k}., for which we expect a negative sign.

In order to test our arguments about the role that KETS can have in regional branching, we refer again to the notion of RTA and first count 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. Sticking again to a time-lag of 5 years (and still with robustness checks for other lags), $KETS\_RTA_{it-5}$ is thus taken as a proxy for the generic KETS knowledge that the region is able to master. In order to detect possible heterogeneity among them, the same indicator is then replicated by referring to the number of IPC classes pertaining to each of the six KETS separately considered. In both cases, the KETS variables are considered in additive terms and, in order to test our hypothesis about their effect on the binding role of technological relatedness, as a moderating variable of $Dens_{ist}$. In investigating the intertwining of regional branching and KETS, it is worth noting that a new regional specialization in *GREEN* may be triggered by KETS, for the fact that some *GREEN* are KETS themselves. In order to control for this confounding effect, we include a dummy variable in the model (*Dummy_KETS*), which is equal to 1 if the s technology of the dependent variable is also a KETS, and 0 otherwise.

The list of independent variables is completed by the inclusion of a number of regional controls. First of all, we controlled for the "technological" drivers of new regional specializations by including the (lagged log of the) R&D intensity of the focal region, $R\&D_{it-5}$, defined as the ratio between its R&D expenditure and its gross value added. As for the other controls, we included in the estimated the (lagged logarithm of) regional employment, $Employment_{it-5}$.

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 TABLE 2 and 3 ABOUT HERE <<<

3.3 Econometric strategy

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

$NewRTA\_GREEN_{ist}$ = f($Dens_{it}$, RTA_GREEN_{it-k}, $Dens_{it}$*RTA_GREEN_{it-k}, $KETS\_RTA_{it-k}$, $Dens_{it}$*$KETS\_RTA_{it-k}$, *Dummy_KETS*, RD_{it-k}, *dtime, dregion*, ε)

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 themselves and the technological relatedness of the new technologies to the pre-existing ones, $Dens_{ist}$. Indeed, 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, $Dens_{ist}$ should have on $NewRTA\_GREEN_{ist}$.

By the same token, previous specialization in green technologies (RTA_GREEN_{it-5}) is expected to exert a positive effect on the emergence of new (green) technological specialization. However, this previous experience is also expected to make the technological relatedness to the past regional technological portfolio ($Dens_{ist}$) less binding for the acquisition of new green specialization. Accordingly, we include the interaction between $Stock\_GTRTA_{it-5}$ and $Dens_{ist}$ in the model, which is expected to yield a negative coefficient.

Estimation of Eq. (1) is not straightforward, as it is characterized by a dichotomous-dependent variable. In line with previous contributions (see Montresor and Quatraro, 2017), we have opted to estimate it using a linear probability model: 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.[2]

4 Results

The results of the econometric estimations with respect to KETS in general are reported in Table 4, starting with a baseline model (Column 1) including the two standard variables of regional branching ($Dens_{ist}$ and RTA_GREEN_{it-5}), from which we obtain supporting evidence for our argument. In line with previous evidence (van den Berge and Weterings, 2013), $Dens_{it}$ actually shows a positive and significant coefficient, suggesting that the emergence of a new green specialization is favoured by its relatedness to the existing technologies of the region. Also the previous stock of green technologies (RTA_GREEN_{it-5}) yields a positive and significant

[2] For the sake of robustness, especially in front of the fact that the estimated coefficients may imply probabilities that are outside the interval [0,1] (Cox, 1970), we have also run a GMM model, whose results (available from the authors at request) are consistent.

coefficient, suggesting that path-dependency matters also in the accumulation of competences in the green realm.

In order to go deeper in the analysis of this gradual process of green learning, in Column 2 we add to the baseline the interaction between $Dens_{ist}$ and RTA_GREEN_{it-5}. The coefficient of each of the two variables in isolation is positive and significant, as in the previous model. On the other hand, the coefficient of the interaction term is negative, providing an important new specification to the supported argument of green branching. Not only help the presence of green technologies the acquisition of new ones, but it also makes their technological relatedness less constraining, pointing to a role that we have theoretically recognised to KETS.

>>> INSERT TABLE 4 ABOUT HERE <<<

In this last respect, in column (3) we include both $KETS\_RTA_{it-5}$ and its interaction with $Dens_{ist}$, and obtain supporting evidence about our hypothesis of the intertwining of KETS and green regional branching. First of all, KETS do appear a significant driver of the region's capacity to master the control of new sustainable technologies, suggesting that the "enabling" role that has been found for them with respect to regional branching in general (Montresor and Quatraro, 2017) extends also to the specific domain at stake. This specification is indeed important, as it provides regions willing to approach a path of sustainable development with an extra, and "general purpose" leverage to do so, in addition to that of their pre-existing green experience. As much important is the negative sign of the interaction between $KETS\_RTA_{it-5}$ and $Dens_{ist}$, suggesting that not only are KETS an important companion of previous environmental competencies, but that they can even make environmental sustainability less constrained by its interconnection with the latter. As we said, by making use of KETS knowledge, regions could become able to re-combine their existing knowledge more innovatively and get to a green specialisation even less related to it.

Interesting results are obtained when, in Columns 4 and 5, we further augment the baseline model by controlling for the economic (via the lag logarithm of $Employment_{it-5}$) and the "technological" (via the lag logarithm of $R\&D_{it-5}$) size of the regions. While the focal variables of regional branching and KETS, along with their interaction with $Dens_{it}$, confirm their previous sign and interpretation, on the other hand, the controls at stake appear negative. These apparently counterintuitive results suggest that regions of a smaller size, and possibly more relying on other innovation modes than the "Science and Technology Innovation" (STI) one (Marzucchi and Montresor, 2017), could have an advantage in acquiring a new green specialisation: a hint about the informal character of this process, which deserves further scrutiny in future research.

Finally, given the significance of the term *Dummy_KETS* in model (3), in Column 7 we exclude from the computation of the dependent variable, *NewRTA_GREEN*, the green technologies related to patent codes that are also classified as KETS (and accordingly exclude the dummy itself). Results appear robust also to this last specification, showing that KETS are able to spur the regional acquisition of green technologies outside of their defining boundaries, and further supporting their capacity of mitigating the gradual and related nature of the relative learning process.[3]

While sharing the common features of being, according to the EC policy makers, technologies that "ensure the competitiveness of European industries in the knowledge economy" (EC, 2009), it is evident that the six KETS are inherently diverse among them: for example, in terms of stage of their life cycle and industries/countries of main diffusion. 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 that, according to their identification (see EC, 2012c, 2012d), are closer to an environmental application, that is, advanced materials, and advanced manufacturing technologies. In order to investigate this issue, Table 5 reports the estimations of our benchamark model for each and every of the six KETS taken individually.[4]

>>> INSERT TABLE 5 ABOUT HERE <<<

Quite interestingly, all of the six KETS are featured by a positive and significant coefficient. What is more, the same applies to their interaction with $Dens_{it}$, showing that the role of KETS in green regional branching is related to the horizontal GPT properties that they share, rather than to their specific, "vertical" application field. This is somehow confirmed by the fact that, quite unexpectedly, the two KETS with the most evident environmental declination, that is advanced materials and advanced technologies, do not appear to play the largest enabling role in comparison to the other: indeed, it rather seems nanotech that exerts the strongest impact on the generation of green technologies, and that contrasts the effect of $Dens_{it}$ to the greatest extent.

The remaining results are also consistent with those obtained with respect to KETS in general. In particular, a previous experience of green knowledge (GREEN_RTA) accompanies each and every of the six KETS in favouring the region's entry in the green realm, and shares with each and every of it a negative moderating role on the effect of technological relatedness. All in all, this provides us with a robust argument about the intertwining of gradual and recombinatory processes in the regional approach to green technologies and sustainability.

[3] Results (available from the authors at request) are also robust to the specification of alternative lags for the retained explanatory variables.

[4] In Table 5, the six KETS are codified as follows: industrial biotechnology (KETS_1), nanotechnology (KETS_2), micro- and nano-electronics (KETS_3), photonics (KETS_4), advanced materials (KETS_5), and advanced manufacturing technologies (KETS_6).

5 Conclusions

Connecting smart and sustainable growth is a policy recommendation that European regions are asked to tackle with increasing urgency (EC, 2012a). The pressures posed by climate change, environmental risks, energy and resource scarcity, actually require regions to increase their mastering of new green technologies and environmentally sustainable processes. In turn, these advancements should not come out of blue, and rather benefit from regions' entrepreneurial capacity of setting research and innovation at work in strengthening and extending their existing knowledge base and distinguishing specialisation patterns.

In spite of its policy relevance, research on the mechanisms through which regions eco-innovate and come to control new environmental technologies, which enable them to approach a sustainable pattern of growth, is still scanty. In particular, little evidence exists on the extent at which this could be driven by the pre-existing knowledge-base of regions and, even less, on the General Purpose Technologies they could use in recombining and extending it to new green applications.

Drawing on the literature on regional branching, we have tried to fill this gap by investigating the process through which regions specialise intro new green technologies. In particular, while claiming that the relatedness of the new green specialisations to the existing ones can make this process more viable, we have also argued that general purpose technologies, like KETS, could assist regions in its undertaking and could even enable them to make the process less bounded by the existing technological paradigm.

The empirical application we have run with respect to 312 NUTS2 regions of 27 EU countries over the period 1981-2010 confirm our research hypotheses. On the one hand, regions do show an incremental and path-dependent approach to environmental sustainability, as their previous experience of green technologies and the relatedness of the new ones both behave according to the regional branching thesis. In policy terms, this suggests that, as claimed by the European policy-makers, sustainability actually seems to connect with smartness in the meaning of RIS3, and that RIS3 thus appears a research grounded connecting policy between the two objectives.

On the other hand, KETS play a similar role to that of previous green experience in favouring the acquisition of new environmental technologies, and in this way makes an eventual lack of the former less problematic. In the same respect, it emerges that KETS do also attenuate the impact of technological relatedness on green regional branching and, in so doing, they increases the extent to which regions can specialise into new sustainable technologies, even when they have a poor endowment of green knowledge. The policy implication of this results is straightforward and quite important: integrating KETS in the RIS3 tool-box could help inexpert green regions to enter in the environmental realm and makes this entry less "exclusive".

Quite interestingly, previous results hold true even when the acquisition of non-KETS related green technologies is considered, as well as when each and every of the six KETS identified by the European policy makers is taken in isolation. This seems to confirm that the role KETS play in green regional branching is actually due to the "rare properties" (Foray, 2009, p. 21) of their horizontal application throughout the knowledge-base of a national/regional economy, and of the complementarity between inventions and applications in their development (Bresnahan, 2010): two properties that appear crucial also in connecting regional smartness and sustainability.

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. Third, the identification of green technologies could be further refined by contrasting the used taxonomy with some new ones that are becoming available. Last, but not least, the list of controls should be augmented, in particular by going beyond regional dummies in capturing the role of environmental regulations and of their stringency (in particular, by looking at OECD EPS), as a key determinants of eco-innovations also at the regional level.

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Table 1 - Definition of variables

Variables	*Definition*	*Source*
$NewRTA\_GREEN_{ist}$	Dummy variable identifying the emergence of a new technological specialization in green technology (GT) *s*, which were observed at time *t* but not at time *t-5*, in region *i*	Our own elaborations on OECD RegPat Database (July 2014).
$Dens_{ist}$	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-1*.	Our own elaborations on OECD RegPat Database (July 2014).
$KETS\_RTA_{it-5}$	Number of KETs in which region *i* is technologically specialised at time *t-5*.	Our own elaborations on OECD RegPat Database (July 2014); EC (2011).
Dummy_KETS	Dummy variable identifying whether the GT is also a KET or not	Our own elaborations on OECD RegPat Database (July 2014); EC (2011).
RTA_GREEN_{it-5}	Number of GTs in which region *i* is technologically specialised at time *t-5*.	Our own elaborations on OECD RegPat Database (July 2014); EC (2011).
$Employment_{it-5}$	Logarithm of employment level in region *i* at time *t-5*.	Cambridge Econometrics (December 2014)
$R\&D_{it-5}$	Logarithm of the ratio between regional R&D expenditure and gross value added	Our own elaborations on Eurostat and Cambridge Econometrics Databases.

Table 2 - Descriptive statistics

	N	*mean*	*max*	*min*	*sd*	*skewness*	*kurtosis*
$NewRTA\_GREEN_{ist}$	1183104	0.063153	1	0	0.243239	3.591919	13.90188
$Dens_{ist}$	1172808	0.175151	1	0	0.14811	0.625055	3.202272
$KETS\_RTA_{it-5}$	1183104	148.9893	1644	0	238.0846	2.726381	12.17829
$Dens_{ist}$ * $KETS\_RTAi_{t-5}$	1183104	32.74562	1514	0	66.34384	3.513782	19.43904
$Dens_{ist}$ * RTA_GREEN_{it-5}	977184	1.397014	30	0	2.714667	2.897251	13.98275
Dummy_KETS	1183104	0.140823	1	0	0.347839	2.065194	5.265028
RTA_GREEN_{it-5}	1183104	4.420065	30	0	7.057235	1.813909	5.654899
$Employment_{it-5}$	957480	7.048902	9.361949	0	0.865198	-0.90649	6.574712
$R\&D_{it-5}$	465152	0.044265	0.371228	0.000598	0.049898	2.195746	9.157134

Table 3 - Pairwise correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) $NewRTA\_GREEN_{ist}$	1								
(2) $Dens_{ist}$	0.2383*	1							
(3) $KETS\_RTA_{it-5}$	0.0640*	0.4528*	1						
(4) $Dens_{ist}$ * $KETS\_RTAi_{t-5}$	0.1297*	0.5385*	0.9108*	1					
(5) $Dens_{ist}$ * RTA_GREEN_{it-5}	0.2098*	0.6535*	0.2996*	0.4382*	1				
(6) $Dummy\_KETS$	0.0179*	0.0154*	0	0.0079*	0.0216*	1			
(7) RTA_GREEN_{it-5}	0.2364*	0.5599*	0.3081*	0.3893*	0.9181*	0.0513*	1		
(8) $Employment_{it-5}$	0.0582*	0.3797*	0.4721*	0.4620*	0.2220*	0	0.2050*	1	
(9) $R\&D_{it-5}$	0.0290*	0.2791*	0.5953*	0.5041*	0.1527*	0	0.1918*	0.1980*	1

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

Table 4 – Green regional branching and KETS in general

	(1) Full Sample	(2) Full Sample	(3) Full Sample	(4) Full Sample	(5) Full Sample	(6) No KETS GREEN
$Dens_{ist}$	0.8299^{***}	1.2247^{***}	0.9436^{***}	0.9529^{***}	1.0471^{***}	0.9242^{***}
	(0.0220)	(0.0200)	(0.0266)	(0.0287)	(0.0365)	(0.0287)
RTA_GREEN_{it-5}	0.0046^{***}	0.0184^{***}	0.0046^{***}	0.0042^{***}	0.0028^{***}	0.0043^{***}
	(0.0003)	(0.0004)	(0.0003)	(0.0003)	(0.0002)	(0.0003)
*$Dens_{ist}$ * RTA_GREEN_{it-5}*		-0.0454^{***}				
		(0.0011)				
$KETS\_RTA_{it-5}$			0.0001^{***}	0.0002^{***}	0.0002^{***}	0.0002^{***}
			(0.0000)	(0.0000)	(0.0000)	(0.0000)
*$Dens_{ist}$ * $KETS\_RTAi_{t-5}$*			-0.0006^{***}	-0.0006^{***}	-0.0006^{***}	-0.0005^{***}
			(0.0001)	(0.0001)	(0.0001)	(0.0001)
Dummy_KETS			0.0055^{***}	0.0041^{***}	0.0047^{***}	
			(0.0011)	(0.0013)	(0.0017)	
$Employment_{it-5}$				-0.0088^{**}		-0.0082^{*}
				(0.0044)		(0.0045)
$R\&D_{it-5}$					-0.6167^{**}	
					(0.2709)	
_cons	-0.0015	-0.1480^{***}	-0.0161^{***}	0.0461^{***}	-0.1458^{***}	-0.2136^{***}
	(0.0042)	(0.0050)	(0.0052)	(0.0152)	(0.0082)	(0.0485)
N	977184	977184	977184	784341	471792	674365
R^2	0.099	0.119	0.100	0.092	0.081	0.096
adj. R^2	0.0984	0.1185	0.1001	0.0913	0.0802	0.0958

Table 5 – Green regional branching and individual KETS

	(1)	(2)	(3)	(4)	(5)	(6)
$Dens_{ist}$	1.3134***	1.2646***	1.2892***	1.3049***	1.2924***	1.3187***
	(0.0243)	(0.0212)	(0.0226)	(0.0223)	(0.0238)	(0.0231)
$KETS\_1\_RTA_{it-5}$	0.0011***					
	(0.0001)					
$Dens_{ist}$ * $KETS\_1\_RTA_{it-5}$	-0.0029***					
	(0.0003)					
$KETS\_2\_RTA_{it-5}$		0.0224***				
		(0.0033)				
$Dens_{ist}$ * $KETS\_2\_RTA_{it-5}$		-0.0599***				
		(0.0100)				
$KETS\_3\_RTA_{it-5}$			0.0009***			
			(0.0001)			
$Dens_{ist}$ * $KETS\_3\_RTA_{it-5}$			-0.0023***			
			(0.0003)			
$KETS\_4\_RTA_{it-5}$				0.0014***		
				(0.0002)		
$Dens_{ist}$ * $KETS\_4\_RTA_{it-5}$				-0.0036***		
				(0.0003)		
$KETS\_5\_RTA_{it-5}$					0.0004***	
					(0.0001)	
$Dens_{ist}$ * $KETS\_5\_RTA_{it-5}$					-0.0010***	
					(0.0001)	
$KETS\_6\_RTA_{it-5}$						0.0005***
						(0.0000)
$Dens_{ist}$ * $KETS\_6\_RTA_{it-5}$						-0.0010***
						(0.0001)
Dummy_KET	-0.0062***	-0.0062***	-0.0060***	-0.0059***	-0.0060***	-0.0059***
	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)
$GREEN\_RTA_{it-5}$	0.0184***	0.0186***	0.0186***	0.0185***	0.0185***	0.0185***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
$Dens_{ist}$ * RTA_GREEN_{it-5}	-0.0452***	-0.0459***	-0.0458***	-0.0457***	-0.0455***	-0.0454***
	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0013)	(0.0012)
$Employment_{it-5}$	-0.0093*	-0.0089*	-0.0090*	-0.0084*	-0.0083*	-0.0090*
	(0.0050)	(0.0048)	(0.0049)	(0.0049)	(0.0048)	(0.0050)
Constant	-0.2265***	0.1066***	0.0385**	0.0369**	0.0356**	0.0397**
	(0.0480)	(0.0395)	(0.0167)	(0.0168)	(0.0164)	(0.0170)
N	784341	784341	784341	784341	784341	784341
R^2	0.111	0.110	0.111	0.111	0.110	0.111
adj. R^2	0.1104	0.1101	0.1103	0.1105	0.1102	0.1106

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$