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Green technological diversification and regional recombinant capabilities: the role of technological novelty and academic inventors

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ABSTRACT

We study the entry of regions in new green technological specializations, specifically investigating the role of recombinant novelty and academic inventors and the interplay between the two. We conduct an empirical analysis on a panel of Italian NUTS-3 regions observed from 1999 to 2009. The results show that both recombinant novelty and the presence of academic inventors are positively associated with new entries in green technological specializations, and that their interaction provides a compensatory mechanism in regions lacking adequate novel combinatorial capabilities. The findings of this study are relevant for policymakers involved in the elaboration of successful regional specialization strategies in green technological domains.

KEYWORDS

green specialization; recombinant novelty; academic inventors

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1. INTRODUCTION

The last report released by the United Nations' International Panel on Climate Change (IPCC) stresses the dramatic conditions concerning the state of the environment due to the impact of anthropogenic activities. The evidence calls for urgent actions aiming at significantly cutting emissions and reducing the exploitation of natural resources. Policies, infrastructure and technologies are deemed to be crucial in this respect (IPCC, 2022).

Concerns about climate change have been at the core of the policy and academic debates for several decades. Scholars have long stressed the enabling role of innovation in support of firms' adaptation and mitigation strategies. With this respect, eco-innovation refers to any kind of change, technological as well as non-technological, aimed at reducing the environmental risk of economic activities (Barbieri et al., 2016; Kemp & Pearson, 2007).

Earlier studies on the causes and effects of green technologies (GTs) have investigated drivers and impacts of their generation and adoption, particularly at the firm level. Environmental regulation has received particular attention in this context, in view of the well-established empirical evidence about its role as an incentive for firms to invest in eco-innovations to improve their economic and environmental performances (Porter & Van der Linde, 1995; Rennings, 2000). In addition, some initial attention has been dedicated to the antecedents of GTs, referring to the knowledge-related dynamics behind their generation and how these affect their distribution across regions (e.g., Del Río González, 2009; Orsatti et al., 2020a; Quatraro & Scandura, 2019).

A new set of studies has recently emerged, analysing these issues through the lenses of the geography of eco-innovation, hence focusing on geographical differences in the patterns of generation of green innovation. Many authors have underlined the importance of regional heterogeneities in the generation of eco-innovations by local firms, most notably when it comes to GTs. Previous literature has thus started investigating the causes of these differences, as well as of different specialization paths in green domains (e.g., Ghisetti & Quatraro, 2013, 2017; Horbach et al., 2012; Orsatti et al., 2020b).

Yet, scarce attention has been paid to the factors that affect the capacity of regions to open new technological trajectories in the green domain. Recent studies have started exploring these dynamics within the context of the evolutionary economic geography approach. While investigating the emergence of technological specialization in the fuel-cell industry in European regions, Tanner (2014) found that regional dynamics are driven by firm-level diversification, whereby the major sources of new

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knowledge are non-industrial actors, in particular universities and public research institutions. Importantly, the evidence suggests that relatedness has not been considered the only driving force behind diversification in that domain. Following this study, recent literature has investigated the impact of other technological or institutional drivers, such as the concurrent regional technological specialization in the domain of key enabling technologies, or the strength of political support to environmental protection policies (Montresor & Quatraro, 2020; Santoalha & Boschma, 2021).

This study contributes to this strand of the literature by improving the understanding of the channels underpinning the entry of regions in new technological specializations in the green domain. In doing so, it extends previous contributions by investigating (1) how regional capabilities handle technological novelty and (2) how the involvement of academic inventors in patenting dynamics is related to the level of regions' entry in new green technological specializations.

Building on the regional branching literature, we exploit the concept of recombinant capabilities (Carnabuci & Operti, 2013) and apply it to the regional level, hence introducing the concept of *regional recombinant capabilities*. We propose a conceptual framework that blends this approach with the recent literature on the intrinsic complexity of green innovation. We hypothesize that the capability of local actors to master uncommon and unprecedented combinations of knowledge components is positively associated with the entry of regions in new green technological specializations (Barbieri et al., 2020; Orsatti et al., 2020a, 2020b). This marks a clear step forward with respect to the extant literature, which has so far mainly focused on the impact of different configurations of local knowledge bases on green technological change (e.g., Colombelli & Quatraro, 2019; Montresor & Quatraro, 2020), without delving into the role of combinatorial capabilities of local agents that lead to technological novelty. Second, we argue that local green technological specializations benefit from the involvement of academic inventors in patenting dynamics in local contexts, in view of their recognized capacity to pursue boundary-spanning research (Quatraro & Scandura, 2019). Lastly, we elaborate on the possible interplay between regional recombinant capabilities and academic inventors (Orsatti et al., 2021).

The empirical analysis focuses on the emergence of new related technology advantage (RTA) in green technological domains at the Italian NUTS-3 level. It uses panel data on 103 Italian NUTS-3 regions observed from 1999 to 2009, combining data from the Organisation for Economic Co-operation and Development's (OECD) RegPat, the 'Academic Patenting in Europe' database and the Cambridge Econometrics European Regional Database.

The paper is organized as follows. Section 2 presents the theoretical framework and spells out the empirical hypotheses. Section 3 describes the data, the variables and the empirical methodology. Section 4 shows the results. Section 5 concludes.

2. LITERATURE AND HYPOTHESES

2.1. Regional capabilities and the greening of the economy

Regions show large dissimilarities in their capacity to grow new economic activities, particularly in green fields. The literature emphasizes an uneven distribution of green specializations across regions in both the United States and Europe (Barbieri & Consoli, 2019; Corradini, 2019; Montresor & Quatraro, 2020; Santoalha & Boschma, 2021; Tanner, 2014, 2016). Therefore, it is worth understanding which local factors (or the lack thereof) influence green diversification and drive differences across territories. While there is substantial empirical evidence pointing to the key role of regional capabilities in the process of regional diversification, the effect of regional capabilities on directing diversification towards sustainable technologies has received scant attention (Boschma, 2017; Santoalha & Boschma, 2021).

The literature on knowledge relatedness has gained importance in this context. Several studies documented that new environmental activities develop more frequently in areas showing local incidence of green-connected activities. For instance, Tanner (2014, 2016) showed robust evidence of a positive relationship between relatedness and the emergence of the new fuel cell industry in European regions, and of the importance of access to local research activities, user industries and academic institutions. Van den Berge and Weterings (2014) provided empirical evidence that the likelihood of introducing new environmental technologies in EU regions depends on extant technologies developed in connected fields. Similarly, Montresor and Quatraro (2020) estimated a positive correlation between technological relatedness to local green and non-green knowledge and the appearance of new green technological specializations in EU-15 regions.

Another branch of studies highlights the relevance of the recombinant knowledge approach for green innovation (Barbieri et al., 2020; Orsatti et al., 2020a; Quatraro & Scandura, 2019; Zeppini & van den Bergh, 2011). These studies have underlined several peculiar traits of eco-innovation processes. For instance, Zeppini and van den Bergh (2011) propose an original model where the generation of GTs is based on combinatorial processes across heterogeneous and weakly related niches of the knowledge space. This is because combinations amongst 'distant' technological pieces more likely cause a paradigmatic shift from a traditional regime (non-green) to a cleaner one (Fleming, 2001; Nightingale, 1998). Additionally, many studies using patent data show that GTs are characterized by higher technological complexity than traditional technologies. The recombination of technological pieces they rely upon are often novel or rarely attempted before (Barbieri et al., 2020; Messeni-Petruzzelli et al., 2011).

Unsurprisingly, collective invention dynamics are fundamental in green domains' innovation activities. Teams formed by researchers with heterogeneous backgrounds or specifically trained and skilled to effectively explore extensive areas of the knowledge space better manage the access to loosely related external knowledge components (Quatraro & Scandura, 2019). Inventor teams' recombinant capabilities are highly relevant in this framework. The concept of recombinant capabilities refers to the ability of individuals to manage novel recombinations through recombinant reuse or creation dynamics (Carnabuci & Operti, 2013).[1] This latter ability is key in enhancing the capacity of generating GTs (Orsatti et al., 2020a). Extending the recombinant capabilities and collective inventions frameworks to the regional domain provides an original and promising setting to address the relationship between technological novelty and the greening of the economy from an economic geography perspective.

2.2. The role of regional *recombinant* capabilities

The concept of *regional innovation capabilities* is pivotal in the framework that we propose in this paper. These refer to the capacity of institutions and local agents to master and coordinate systemic interactions to produce new knowledge (Foss, 1996; Lawson & Lorenz, 1999; Romijn & Albu, 2002). Over time, recombinant capabilities develop from expanding innovation activities within economic systems and learning dynamics that foster local agents' capacity to combine internal and external inputs (Quatraro, 2009).

The recognition of the recombinant dynamics leading to innovation activities calls for the improvement of this framework, introducing the concept of *regional recombinant capabilities* as the ability of local innovation ecosystems to stimulate combinatorial attempts that lead to novelties. Regional innovation systems feature a variety of institutional and non-institutional actors, whose networks of interactions are crucial to activate innovation dynamics depending on learning practices leading to knowledge and skills accumulation (Cooke, 2001). Therefore, understanding the generation process of new technologies at the regional scale requires recognizing that systemic interactions and localized learning dynamics can start new and unique combinatorial attempts, rather than the simple refinement and improvement of established knowledge combinations.

Extending the distinction between recombinant reuse and recombinant creation capabilities to the regional context provides a fruitful setting to identify and qualify the local dynamics behind creating new technological paths (Martin & Sunley, 2006). Thus, transplantation occurs not simply by importing knowledge from other regions but also different parts of the knowledge space. Indeed, the ability to creatively connect knowledge components by attempting novel combinations, that is, recombinant creation, is a sort of transplantation itself.

It is realistic to consider regional recombinant creation dynamics as a critical driver of new specializations in green technological domains. In other words, new green specializations are very likely the outcome of the effort to disclose new and unexplored local technological paths. Therefore, recent efforts to depict regional knowledge production in terms of the novelty degree are crucial. Part of the geography of innovation literature investigates the determinants of regional heterogeneity in the emergence of novelties (or breakthroughs) and how local novelty correlates with the main geographical features, for example, city size (Castaldi et al., 2015; Mewes, 2019). This branch of literature mainly exploits information contained in patent data, looking at the co-occurrences of technological classes to identify regional novelty (i.e., patents showing *atypical* combinations). It largely finds that recombinant novelty is linked to knowledge bases with relatively high intensity of unrelated variety. Unsurprisingly, large cities are the geographical context where recombinant novelty is more likely to arise.

Extant literature stresses the importance of two drivers of regional green innovation: (1) the heterogeneity of local knowledge bases (e.g., Quatraro & Scandura, 2019) and (2) the local availability of competences favouring the recombination of knowledge inputs loosely related and disseminated across the knowledge space (e.g., Ocampo-Corrales et al., 2021; Orsatti et al., 2021). Traditionally, local capabilities imply a long process of historical knowledge accumulation based on continuous experimentation and learning. Yet, the pressure to reduce environmental risks associated with economic activities and the recent high regulatory stringency have caused a steep upsurge in demand for GTs, a highly profitable new business (Colombelli et al., 2020). Regions showing scant recombinant creation capabilities are therefore likely to be worse off in the green technological race. On the contrary, the local availability of recombinant creation capabilities offers a fruitful opportunity to conduct research and development (R&D) in new technologies for abating environmental risks successfully.

In view of these arguments, we postulate that higher levels of recombinant creation capabilities inside regions lead to higher levels of new green specializations; hence we put forward the first hypothesis of this study:

> *Hypothesis 1: The amount of new green specializations is positively related to the level of regional recombinant creation capabilities.*

2.3. The role of academic inventors

Green innovations are characterized by intrinsic higher complexity, which arises because such type of innovation relies on the combination and integration of several new and heterogeneous knowledge and technological components (Messeni-Petruzzelli et al., 2011; Orsatti et al., 2020a). The complexity and novelty of green innovation so-conceived require skills and information that are frequently distant from the own industry knowledge base and entail complex tasks to be performed (De Marchi, 2012; Messeni-Petruzzelli et al., 2011).

These features bring the role of collective invention at the centre of the debate. Inventing in green domains requires a considerable reliance on external knowledge generated by a variety of organizations. Collaborations among heterogeneous institutional actors, which are sources of a variety of specialist competences and knowledge, are therefore crucial for fostering green innovation (Cainelli et al., 2012, 2015; De Marchi, 2012; De Marchi & Grandinetti, 2013).

Specifically, recent studies have documented that collaboration with academic institutions is a key source of comparative advantage in conducting green-related R&D, as it is essential for increasing technological radicalness and novelty. Cainelli et al. (2012) show that collaboration and networking with academia are critical for firms inventing in radical and relatively young technologies, like environmental ones. De Marchi and Grandinetti (2013) provides a similar result, showing that the development of environmental technologies is more sensitive to collaborations with universities and research centres, as compared with standard innovation. Triguero et al. (2013) show that European small and medium-sized enterprises (SMEs) cooperating with various institutional actors (including universities) are more productive in terms of green patenting. Fabrizi et al. (2018) confirm that the role of public research centres and universities for green research networks is helpful and more effective than the role of private firms across European Union (EU) countries.

These studies corroborate the argument that specializations in green domains require a wide set of heterogeneous skills and competences; therefore, collaborations with 'high profile' partners endowed with those assets is fundamental to successfully innovating in green domains. Such argument clearly relies on the widely accepted stylized fact about the important role of universities for firms' innovation activities and, more generally, for technological advance and economic growth (e.g., Adams, 1990; Dasgupta & David, 1994; Jaffe, 1989).

The grafting of the knowledge-base approach onto the analysis of regional technological diversification in green domains can help shedding further light on the crucial role of academic inventors. This approach stresses the relevance of combinatorial dynamics in regional innovation dynamics, and in particular it emphasizes the difference between analytical and synthetic knowledge bases in explaining the peculiarity of industry-specific innovation patterns (Asheim et al., 2017; Grillitsch et al., 2018). Accordingly, eco-innovations rely on an analytical knowledge base, characterized by a high content of scientific knowledge grounded on scientific laws and models highly subject to codification (Marzucchi & Montresor, 2017; Ocampo-Corrales et al., 2021). In applying the knowledge base approach to understand knowledge flows patterns in the green domain, Ocampo-Corrales et al. (2021) argue that renewable energies benefit intensively from knowledge sourced from the world of science. Scientific knowledge sourced from epistemic communities of actors and institutions is pivotal as it allows agents to understand the complexity of eco-innovation and contribute to creating new ideas (Ocampo-Corrales et al., 2021; Trajtenberg et al., 1997; Verhoeven et al., 2016).

Against this background, the involvement of inventors from universities in collective dynamics is of particular interest as it represents a direct link between the world of science and industry. Their distinctive role rests on the key drivers of individual creativity and successful inventive collaborations, notably inventors' educational attainment and knowledge breadth (Allen, 1984; Fleming et al., 2007).

As far as educational attainment is concerned, several contributions have shown that inventors with higher levels of education, like academic inventors, address technological problems more efficiently.[2] Gruber et al. (2013) have shown that scientists are more likely to produce inventions crossing technological boundaries than engineers, concluding that inventors with a solid scientific background more effectively master recombination across heterogeneous and unrelated technological areas. In addition, inventors with higher educational achievement acquire a more abstract understanding of technical problem solving (Gruber et al., 2013), hence developing the ability to assimilate technological knowledge from other domains (Gibbons & Johnston, 1974). Academic inventors are also less likely to experience technological lock-ins due to cognitive constraints and are more inclined to engage in boundary-spanning activities (Gagné & Glaser, 1987; Hambrick & Mason, 1984; Hargadon, 2006; Pelled, 1996; Walsh, 1995). Recent empirical works provide specific empirical evidence on the role of academic inventors in the production of green inventions, based on the core argument that, thanks to their solid scientific background and higher education attainment, academic inventors have the necessary skills to recombine knowledge across heterogeneous technological areas (Orsatti et al., 2021; Quatraro & Scandura, 2019).

Academic inventors' knowledge breadth significantly matters as it determines how the inventive process results in truly path-breaking outcomes (Gruber et al., 2013). Inventors' knowledge breadth becomes particularly important when teamwork is considered. Indeed, part of the advantage of inventor teams as compared with lone inventors is due to higher levels of knowledge variety entailed by teams. Melero and Palomeras (2015) argue that teams including *generalist* inventors outperform teams that include only specialist inventors, and this is especially true in highly uncertain research contexts. Generalist inventors possess a broad knowledge breadth because their prior expertise is distributed among different technological areas. In contrast, specialist inventors are those whose prior expertise is concentrated in a given area. As mentioned earlier in this section, academic inventors typically possess an advanced scientific educational background. This, in turns, results in higher knowledge breadth as compared with their non-academic peers (Gruber et al., 2013): the understanding of general principles and of technological landscapes help academic inventors in the comprehension, analysis and assimilation of distant technological knowledge, hence contributing to widen the breadth of their knowledge base. Against this background, academic inventors can arguably be considered as generalist within inventive teams involving both academic and non-academic inventors.[3]

Generalist inventors lead to better performances in technologically uncertain domains for various reasons. First, they are better in identifying fruitful technological recombinations, as they are better positioned to evaluate the potential alternative connections among knowledge bits from different domains (Melero & Palomeras, 2015). Second, specifically considering collective dynamics, generalist inventors within teams increase the level of expertise in common areas, hence play a knowledge bridging role that is particularly relevant for knowledge recombination (Rulke & Galaskiewicz, 2000). Additionally, according to Melero and Palomeras (2015), generalist inventors reduce communication problems inside teams as well as conflicts related to the divergent perspectives among team members, and limit free-riding problems due to the impossibility to measure individual contributions inside teams. Importantly, the comparative advantage of generalist inventors in the combination of diverse knowledge components is crucial when there is no clear or established structure of combination(s), as it is typically the case for highly uncertain and complex technological contexts.

Recalling the above-discussion on the role of external knowledge and, particularly, knowledge from academia, for green innovation, and following the arguments on the specific role of academic inventors, our claim is that the presence of active academic inventors in local areas bears a positive stimulus on the capability of local innovation systems to enter new green technological specializations. First, given the high level of cumulated human capital required to enter the academia, it is reasonable to assume that academic inventors have higher educational levels than the level of the average inventor employed in industry. This leads to higher capacity to recombine knowledge across a wide range of technological areas, pushing the regions where they are embedded toward new technological specializations. Second, the presence of academic inventors inside teams involved in uncertain technological contexts like the green ones allow reaching better performances, because of the wide knowledge breadth that academic inventors have. This translates into regions entering new green specializations.

In addition to such a direct link between the involvement of academic inventors inside teams and green specializations, we argue that the former also play a role in regional recombinant capabilities. As discussed in section 2.2, the level of local recombinant creation capabilities is a key factor for the greening of local economies, so that areas lacking such capabilities may be disadvantaged as compared with well-endowed areas. In view of their intrinsic capacity to carry out boundary-spanning research and to allow for better performances in technologically uncertain contexts, academic inventors are expected to compensate for the absence or scarcity of recombinant creation capabilities in local areas (Orsatti et al., 2021). While the latter require time to be developed and strengthened, partnerships between academic institutions and other key agents of the innovation ecosystem may lead to the development of new green specializations in a timelier manner. Accordingly, academics will work as injectors when the local private endowment of combinatorial capabilities is limited, hence helping regions to specialize in new GTs to keep the pace with the ecological transition. Conversely, when regions are highly endowed with recombinant capabilities, the marginal contribution of academic inventors for new green specializations is likely to be rather small. Therefore, the involvement of academic inventors in local innovation dynamics will both affect the entry in new green specializations per se and mediate the role of local recombinant capabilities for new green specializations. In other words, academics might work as injectors when the local private endowment of combinatorial capabilities is limited, helping regions to specialize in new GTs to keep the pace with the ecological transition. Conversely, when regions are highly endowed with recombinant capabilities, the marginal contribution of academic inventors for new specializations reduces.

In view of these arguments, we spell out two hypotheses concerning the role of academic inventors on the entry in new green technological specializations:

> *Hypothesis 2a: The amount of new green specializations is positively associated with the involvement of academic inventors in local patenting activity.*

> *Hypothesis 2b: The lower/higher the regional recombinant capabilities, the higher/lower the marginal contribution of academic inventors to the entry of regions in new green specializations.*

3. DATA, VARIABLES AND METHODOLOGY

3.1. Data sources

We conduct the empirical analysis on the 103 Italian NUTS-3 regions observed over the period 1999–2009. We exploit multiple data sources. First, we collect patent data from the OECD's RegPat database. Second, information on Italian academic inventors come from the 'Academic Patenting in Europe' (APE-INV) database. Third, we exploit the Cambridge Econometrics European Regional Database to collect regional administrative data. Additional data come from Legambiente, a well-established Italian not-for-profit environmental organization.

3.2. Variables

3.2.1. Dependent variable

Following previous studies on regional innovative specialization (e.g., Boschma et al., 2013; Colombelli et al., 2014; Montresor & Quatraro, 2017), our dependent variable is the count of entries in new green technological specializations of region i at time t ($NEW\ GREEN\ SPEC_{it}$). To build our dependent variable we count the number of entries in new green specializations that region i shows at time t that were not observed in the same region at time $t-k$. Local green technological specializations are captured with a standard Balassa indicator, redefined in terms of number of patents classified within the list of green Cooperative Patent Classification (CPC) classes, which allows to calculate the so-called RTA. Formally, if i indicates the region, c the patent class and t stands for time, RTA_{ict} takes the following form:

$$RTA_{ict} = \frac{PAT_{ict} / \sum_{i=1}^{n} PAT_{ict}}{TotPAT_{it} / \sum_{i=1}^{n} TotPAT_{it}}$$

where PAT_{ict} is the count of patents in class c filed at time t by inventors who reside in region i; $TotPAT_{it}$is the total number of patents filed at time t by inventors resident in region i. Therefore, if the ratio is greater than 1, region i shows an RTA in class c at time t. We then focus on green RTAs (i.e., RTAs in green CPC) comparing, for each and every region over time, all the green RTAs shown at time t with the green RTAs shown at $t-k$, and we consider only the new ones, which are counted in the variable $NEW\ GREEN\ SPEC_{it}$. To identify green patent CPC classes and build the measures of green RTAs, we combine the CPC classification for GTs with the OECD RegPat database (Maraut et al., 2008). The former provides a precise list of green CPC classes,[4] while the latter allows connecting CPC classes with NUTS-3 regions according to the registered address of the inventors listed in patent documents. Overall, inventors resident in Italian NUTS-3 regions filed 18,030 patents over the period 1999–2009, 10% of which were green patents.

In our preferred specification, we take a six-year window to build our measure of regional entry in new green specializations. This allows to attenuate biases due to the inherent volatility of patent statistics, whereby the emergence of a new RTA in year t may be due to a small count of patent applications in that specific field in the previous year. While being arbitrary to a certain extent, a six-year window is supposedly enough to smooth patent applications' volatility (Montresor & Quatraro, 2017).[5] The descriptive statistics of the dependent variable are reported in Table 1.

3.2.2. Independent variables

We focus on two main explanatory variables, measured at the regional level: (1) the number of patents with at least one novel recombination (RC_{it}) and (2) the presence of academic inventors in patenting activities ($ACAD_{it}$).

We measure local combinatorial novelty relying on the co-occurrence of patent CPC classes between citing and cited patents – the former invented in the regions of interest. We focus on the links between invented patents and related citations to measure novelty because patent citations are (technological) references to prior knowledge on which the patented invention builds (Jaffe et al., 1993; Jaffe & Trajtenberg, 1999; Maurseth & Verspagen, 2002; Trajtenberg, 1990). Hence, if the technology classifying the patent cites a bit of prior art for the first time, this signals a new occurred combinatorial attempt that is likely to deepen the local technology endowment fostering new paths (Fleming, 2001). Precisely, we define as novel-in-recombination a patent linking a CPC class in which it is classified with a CPC class contained in its patent backward citations for the first time in Italy. This measure comes largely from Verhoeven et al. (2016), but we adapt it to the Italian context, providing an original version of combinatorial novelty that also accounts for its regional dimension. Since our focus is on the relationship between local combinatorial novelty in non-green fields and regional entry in new green specializations, we exclude CPC classes related to environmental aspects when calculating regional combinatorial novelty. We assign novel patents to Italian NUTS-3 regions according to the registered address of the inventors listed in patent documents.[6] The descriptive statistics of the variable RC are reported in Table 1.

Our second variable of interest refers to the involvement of academic inventors in local patenting activities. Data on academic inventors come from the APE-INV database, which collects information on patents filed by academics at the European Patent Office (EPO). We restrict the sample to academic inventors residing in Italian NUTS-3 regions. We assign academic patents to NUTS-3 regions according to the address of the academic inventor(s) listed in the patent document (as reported in RegPat), and we construct an indicator taking value 1 for NUTS-3 regions with at least one patent filed by an academic inventor, 0 otherwise (*ACAD*).[7] In our sample, 47% of NUTS-3 regions over time (1999–2009) show active academic inventors (Table 1). Interestingly, the sample of patents whose inventive team involve academic inventors is systematically statistically different with respect to the rest of the patents in terms of various patent quality indicators (see Table A2 in Appendix A in the supplemental data online). Compared with patents not invented by academic inventors, patents involving academics show, on average, higher technological impact; they rely less on pre-existing knowledge stocks and more on non-patent literature; they also show higher complexity, higher relevance for subsequent inventions, higher breadth of the technology fields on which they belong and higher novelty with respect to previous patents they rely upon.[8] Such characteristics of patents invented by teams that include academic inventors point to seemingly superior recombinant capabilities of academics, hence supporting the argument we bring forward with Hypothesis 2.

3.3. Econometric model

We apply an empirical setting that is typical of the regional branching literature, and we extend it by adding the role of academic inventors and that of local recombinant capabilities (as well as their interaction) as drivers of regional entry in new specializations in green technological domains. The model takes the following form:

$$\begin{aligned} NEW\ GREEN\ SPEC_{it} = {} & \alpha + \beta_1 ACAD_{it-1} + \beta_2 RC_{it-1} \\ & + \beta_3 ACAD_{it-1} \times RC_{it-1} \\ & + X_{it-1}\psi' + \phi_t + \varepsilon_{it} \end{aligned}$$

where $NEW\ GREEN\ SPEC_{it}$ is the count of entries in new green specializations of region i at time t; $ACAD_{it-1}$

Table 1. Variable description and descriptive statistics.

Variable	Description	Observations	Mean	SD	Minimum	Maximum
GREEN SPEC ENTRY[a]	Regional count of entries in new green technological specializations (six-year window)	1133	0.85	1.05	0	5.00
RC[a]	Inverse hyperbolic sine (IHS)-transformed regional count of patents with novel recombination	1133	1.13	1.15	0	4.71
ACAD[b]	Dummy = 1 if at least one patent invented by academic inventors in a region; 0 otherwise	1133	0.48	0.50	0	1.00
RTA GREEN[a]	IHS-transformed number of revealed technology advantages in green IPC classes.	1133	0.74	0.75	0	2.64
DENS GREEN[a]	Tech relatedness (density) to green revealed technological advantages (RTAs)	1133	0.04	0.10	0	0.72
DENS NON-GREEN[a]	Tech relatedness (density) to non-green RTAs	1133	0.08	0.15	0	1.12
GDP PC[c]	IHS-transformed level of regional gross domestic product (GDP) per capita	1133	10.01	.27	9.35	10.55
R&D PC[c]	IHS-transformed level of regional research and development (R&D) expenditures per capita	1133	5.27	0.60	3.28	6.38
ENVIRON[d]	Dummy = 1 if a region is above the national annual median of the environmental performance city score; 0 otherwise	927	0.50	0.08	0.21	0.74
PRE-SAMPLE MEAN[a]	Pre-sample mean of *GREEN SPEC ENTRY* (1988–93)	1133	0.43	0.48	0	2.17

Sources: [a]OECD RegPat Database; [b]APE-INV Database; [c]Cambridge Econometrics European Regional Database; and [d]Legambiente.

is a dummy indicator for the involvement of academic inventors in region i at time $t-1$; RC_{it-1} is the measure of local recombinant creation capabilities, that is, the number of patents invented in region i at time $t-1$ showing novel recombination. β_3 captures the effect of the interaction between the presence of academic inventors and the count of novel patents. Following the previous literature, in the baseline specification, X_{it-1} is a vector of the following control variables: (1) the number of revealed GT advantages (*RTA GREEN*), (2) the square of the number of revealed GT advantages ($RTA\ GREEN^2$),[9] (3) the density (relatedness) of GTs (*DENS GREEN*), (4) the density (relatedness) of non-GTs ($DENS\ NON-GREEN$), (5) GDP per capita (*GDP PC*), and (6) R&D per capita (*R&D PC*). We also include the pre-sample mean of the dependent variable ($PRE-SAMPLE\ MEAN$), measured in the 1988–93 period, as an additional control variable (Blundell et al., 2002). As suggested by Castellani et al. (2022), the pre-sample mean is a good measure of time-invariant region fixed-effects. Its inclusion helps accounting for the temporal persistence of the local capacity of enriching the green-tech specialization, which we expect to hold given the usual path dependence of technological development. Lastly, ϕ_t refers to year dummies to account for the shocks common to all Italian NUTS-3 regions. We cluster standard errors at the NUTS-3 level.

In the augmented version of the main empirical specification we also control for the local environmental policy stringency, measured by the index of urban environmental quality developed by an Italian not-for-profit organization called Legambiente. This index ranks the 103 Italian capital–province cities on the basis of several indicators such as air quality, green areas, drinking water quality, energy consumption and waste recycling performance. Therefore, it implicitly provides an evaluation of the local policymakers' performance in managing environmental protection tasks (Bianchini & Revelli, 2013). Accordingly, we build an indicator of environmental policy stringency ($ENVIRON_{it}$) that takes value 1 if the NUTS-3 region is above the national annual median; and 0 otherwise. This information is available from 2001 onwards, hence the number of observations reduces when we add this variable to the baseline specification. Descriptive statistics of all variables are reported in Table 1, while pairwise correlations are in Table A1 in Appendix A in the supplemental data online.

We estimate the above-described model through linear estimators in a panel setting. We also use negative binomial estimators to check the robustness of the estimated coefficients. When using linear estimators, we transform the dependent variable along with *RC*, *RTA GREEN*, *GDP PC* and *R&D PC* through the inverse hyperbolic sine (IHS) transformation.[10] When using negative binomial estimators, the dependent variable is a count variable.

4. RESULTS

4.1. Main results

The main results are reported in Table 2. Columns I–IV refer to linear model estimates, while columns V–VIII refer to negative binomial estimates (coefficients reported as incidence rate ratios – IRR).[11] Both estimation methods provide robust results. We will discuss the results of the linear estimates for ease of interpretation. Looking at the model with no interaction term RC×ACAD (columns I and III), *RC* shows a positive and statistically significant coefficient. Precisely, a 1% increase in the number of local patents showing novel recombination is associated to an increase in the number of entries in new green specializations that ranges between about 6.2% (column III) and about 7.7% (column I). These results provide support Hypothesis 1. As far as *ACAD* is concerned, the estimated coefficients are positive and significant, as expected. In particular, regions where $ACAD = 1$ show, on average, between about 11.7% (column III) and 9.5% (column I) additional new green technological specializations with respect to regions where academic inventors are not involved in the local inventive process. This supports Hypothesis 2a.

Columns II and IV show the results of the model that include the interaction term RC×ACAD. Its coefficients are negative and statistically significant in both cases, in line with Hypothesis 2b. This suggests that the role of academic inventors marginally decreases when regions are increasingly endowed with recombinant creation capabilities. In other words, the importance of academics is expected to increase when regions lack recombinant creation capabilities. Figure 1 plots the linear prediction of entry in new green specializations when academic inventors are either active or not in the region, at different levels of local recombinant creation capabilities (i.e., first quartile, median, mean, third quartile and ninth decile of *RC* distribution). For levels of *RC* below the third quartile, regions where academic inventors are active show higher predicted levels of entry in new green specializations than regions where there are no active academic inventors. The average marginal contribution of academic inventors to regions' entry in new green specialization is positive and significant up to a relatively high level of *RC*. However, such average marginal contribution disappears above the third quartile of *RC*: when regions show the highest levels of *RC*, whether academics are involved or not in patenting activities does not significantly influence the level of entries in new green specializations). Therefore, the involvement of academic inventors in local innovation activities may compensate for low levels of local recombinant creation capabilities. Figure 2 allows one to appreciate the average marginal contribution of academics by plotting the average marginal effects (AMEs) of *ACAD* for different levels of *RC*. Precisely, it plots the AMEs at, respectively, the first quartile, median, mean, third quartile and ninth decile of *RC*. The AME of *ACAD* diminishes when regions show higher levels of *RC*, as evident also from Figure 1, reaching no significant effect when regions are in the third quartile of the distribution of *RC* or above.

In all, such graphical evidence corroborates Hypothesis 2b: the role of academic inventors is particularly relevant when regions lack combinatorial capabilities, while it marginally decreases when the local endowment of *RC* reaches high levels.

With respect to the set of control variables, we estimate positive and significant coefficients for *RTA GREEN* and *PRE − SAMPLE MEAN* in all models, and for *DENS GREEN* in columns I and II only.[12]

4.2. Further analyses and robustness checks

We discuss in this section a set of additional analyses and robustness check. First, we replicate the analysis on Northern and Central–Southern regions separately (see Table B1 in Appendix B in the supplemental data online). This analysis allows the search for spatial heterogeneity, this being a reasonable outcome in a country characterized by a geographical divide such as Italy. The split follows the distribution of GTs across time as in Quatraro and Scandura (2019). Estimates for Northern regions (columns I and II) largely confirm our main findings, while estimates performed on Southern–Central regions alone (columns III and IV) are only partially confirmatory of our findings. Precisely, the latter reveal that only academic inventors seem to play a role in the greening process of Southern–Central Italian regions. This suggests that reinforcing the link between academic institutions and other actors of the local innovation systems may represent a viable strategy for the governance of regions lacking recombinant creation capabilities, but willing to play an active role in the technology-based green transition.[13] Figures B1–B4 provide visual support to the results of Table B1 in Appendix B online.

Second, we perform three different sensitivity checks on the construction of the variable *ACAD*, working out (1) a 0/1 indicator for regions whose count of academic patents is above the national yearly median, (2) a 0/1 dummy for regions above the median of the share of academic patents across Italian NUTS-3 regions, and (3) a 0/1 dummy for regions above the yearly median of the share of academic inventors across Italian NUTS-3 regions. The variables so constructed, which we use alternatively to replace the original variable discussed in section 3.2.2, allow accounting for the local intensity of academic patenting and academic inventors while considering the national scale of the phenomenon. The results, reported in Table B2, columns I–VI, in the supplemental data online fully confirm the main findings, hence reassuring on their reliability.

An additional robustness check is performed on the quality of local academic patents. Specifically, we look at the patent 'originality' as proposed by the OECD Patent Quality Indicators (Squicciarini et al., 2013). Patent originality mirrors the breadth of the technology fields on which patents rely. As pointed out in Appendix A in the supplemental data online, inventions (as well as inventors) relying on many diverse knowledge fields are supposed to lead to original results. Therefore, estimating the role of inventions' originality in our empirical framework should capture the local academic *premium* of technological originality. Operatively, we build an indicator taking value 1 if a region shows an average level of academic patent originality above the national yearly mean of patent originality; and 0 otherwise. The results, shown in Table B2, columns

Table 2. Main results.

	Linear model				Negative binomial (IRR)			
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
RC	0.077**	0.154***	0.062*	0.124**	1.103**	1.336***	1.084*	1.259***
	(0.030)	(0.038)	(0.035)	(0.045)	(0.045)	(0.084)	(0.049)	(0.085)
ACAD	0.095**	0.229***	0.117**	0.224**	1.178**	1.744***	1.218**	1.635***
	(0.047)	(0.060)	(0.053)	(0.070)	(0.098)	(0.220)	(0.108)	(0.222)
RC × ACAD		−0.125***		−0.099**		0.758***		0.805***
		(0.037)		(0.042)		(0.044)		(0.051)
RTA GREEN	0.251**	0.209**	0.234**	0.200**	2.036***	1.813***	1.917***	1.755**
	(0.091)	(0.085)	(0.095)	(0.091)	(0.327)	(0.292)	(0.331)	(0.307)
RTA GREEN^2	−0.070	−0.052	−0.059	−0.044	0.798**	0.838**	0.823**	0.854*
	(0.046)	(0.044)	(0.049)	(0.047)	(0.063)	(0.066)	(0.067)	(0.071)
DENS GREEN	0.388*	0.345*	0.310	0.261	1.716*	1.517	1.593	1.417
	(0.204)	(0.205)	(0.220)	(0.224)	(0.497)	(0.439)	(0.491)	(0.435)
DENS NON-GREEN	−0.247	−0.178	−0.074	−0.028	0.574**	0.626*	0.741	0.781
	(0.205)	(0.212)	(0.225)	(0.232)	(0.153)	(0.169)	(0.204)	(0.217)
GDP PC	0.192	0.155	−0.013	−0.023	1.527*	1.390	1.017	0.989
	(0.161)	(0.154)	(0.193)	(0.186)	(0.363)	(0.332)	(0.287)	(0.277)
R&D PC	−0.007	−0.004	0.031	0.032			2.837	2.380
	(0.057)	(0.053)	(0.071)	(0.068)			(1.813)	(1.520)
LEGAMBIENTE			0.578	0.513	1.412**	1.394**	1.347**	1.336**
			(0.359)	(0.356)	(0.177)	(0.167)	(0.182)	(0.175)
PRE-SAMPLE MEAN	0.257**	0.263**	0.252**	0.257**	1.015	1.045	1.099	1.122
	(0.079)	(0.079)	(0.097)	(0.096)	(0.096)	(0.099)	(0.119)	(0.122)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1133	1133	927	927	1133	1133	927	927
R^2	0.226	0.234	0.209	0.215				
Pseudo-R^2					0.086	0.093	0.076	0.081

Note: Models (I) to (IV) are estimated with linear estimators; models (V) to (VIII) are estimated with negative binomial estimators (coefficients reported as incidence rate ratios – IRR). All models include year fixed effects (FE) and NUTS-3 FE in a flexible way (i.e., including the pre-sample mean of the dependent variable). Standard errors, clustered at the NUTS-3 level, are shown in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.001$.

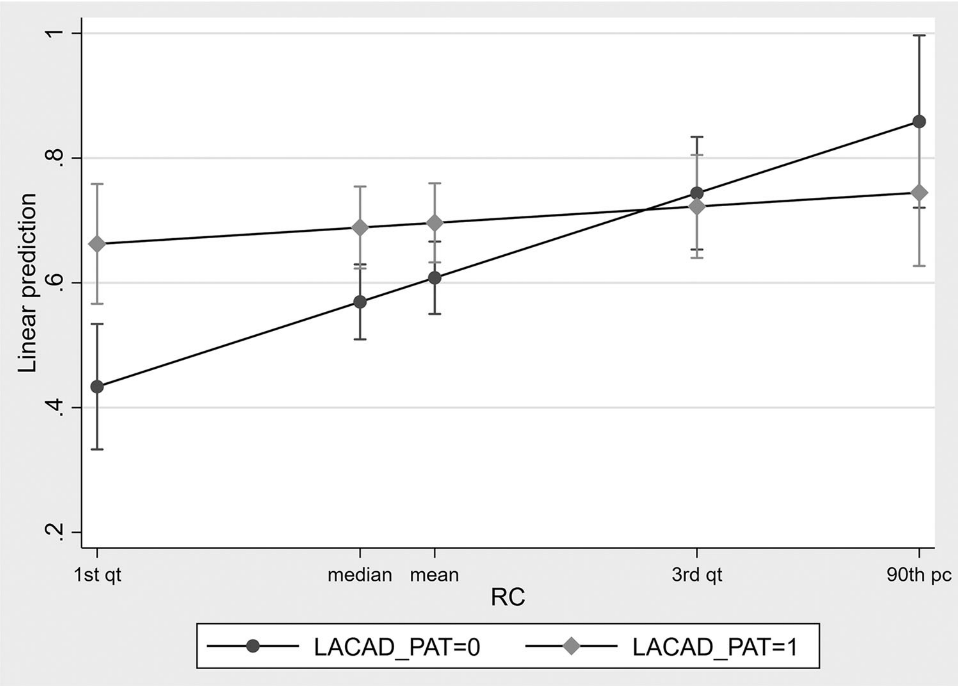

Figure 1. Plot of the linear prediction of entry in new green specializations when academic inventors are either active (squares) or not (circles) in the region, at different levels of local recombinant creation capabilities (i.e., first quartile, median, mean, third quartile and ninth decile of *RC*).

VII and VIII, in Appendix B online are in line with the main findings reported in Table 2. In particular, the positive and significant coefficient of the new variable *ACAD* shows that regions where the academic patenting originality is above the mean have higher rates of entry in new green specializations. In addition, academic originality is mainly relevant when regions lack recombinant novelty capabilities, as shown by the negative and significant coefficient of the interaction term $ACAD \times RC$. In other words, the technological originality of academic inventors compensates for the lack of local recombinant capabilities.

The last robustness check concerns the dependent variable, which we construct by counting new green specializations over three- and five-year windows, respectively, instead of the six-year window used in the main estimates. While the latter allows to account for the inherent

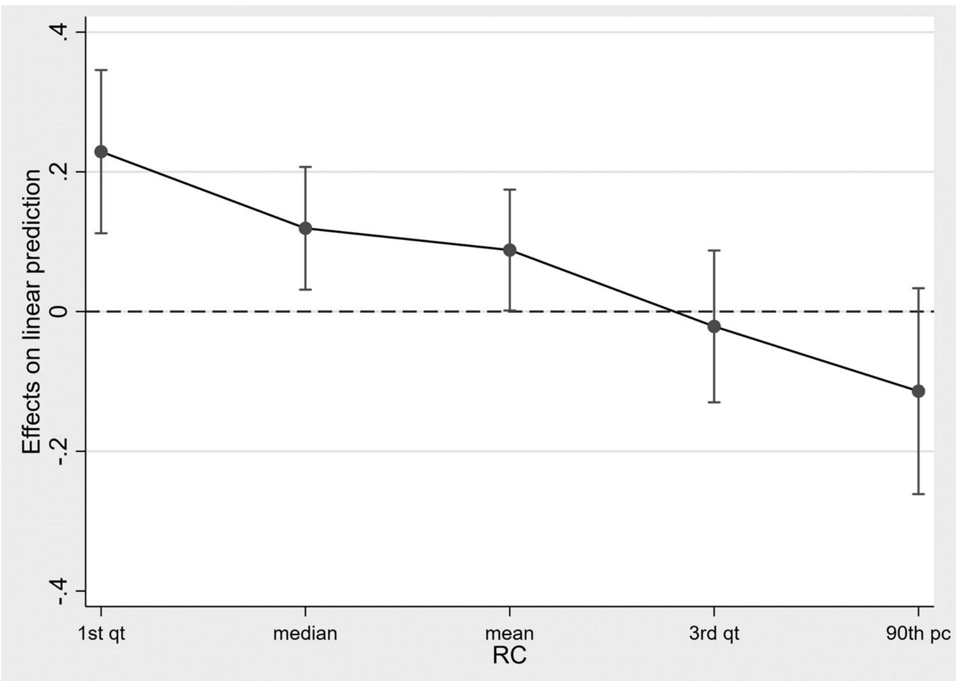

Figure 2. Plot of the average marginal effects (AMEs) of *ACAD* for different levels of *RC* (i.e., first quartile, median, mean, third quartile and ninth decile of *RC*).

volatility of patent activity, shortening it implies getting (more) precise counts of new RTA, yet with the caveat of being potentially driven by the erratic trend of patenting activity. The estimates show that changing the time window to count new green RTAs does not change the main results, which are hence considerably robust (see Table B3 in Appendix B online).

5. CONCLUSIONS

This work has investigated the role of recombinant novelty and academic inventors for regional technological diversification in green areas. We have articulated a conceptual framework blending the recombinant knowledge approach with recent literature on the antecedents of green innovation.

In particular, we have followed extant literature that characterizes innovations in the green domain as, on average, more complex than non-green ones, and that stresses how the generation of green patents relies on the capacity to recombine technologies weakly related to one another (Barbieri et al., 2020; Orsatti et al., 2020a; Zeppini & van den Bergh, 2011). Consequently, we have put forward a research hypothesis stating that the success in the generation of environmental innovation allowing regional green technological diversification relies on the local availability of innovation capabilities that support the recombination of atypical and unprecedented combinations of knowledge components. Second, based on the innovation literature on the role academic knowledge for innovation, particularly in the green domain, we have hypothesized that involving academic scientists in inventor' teams favours green-tech diversification. The reasons relate to the educational attainment of academic inventors, which lead to higher capacity to recombine knowledge across a wide range of technological areas, and to their knowledge breadth, which allows teams where academic inventors are involved to reach better performances in highly uncertain innovation processes like the green ones. Furthermore, we have investigated the interplay between academic inventors and regional recombinant creation capabilities, hypothesizing that the former help to compensate for the lack or scarcity of the latter, thereby supporting the technology-based green transition, particularly in areas showing low levels of novelty creation.

The analysis has focused on the entry in new green specializations of Italian NUTS-3 regions, over the period 1999–2009. Our results provide empirical evidence of robust statistical associations between the level of new green specializations and both the extent of local recombinant creation capabilities and the involvement of academic inventors. The analysis also supports the argument of a compensation effect of academic inventors in areas scarcely endowed with recombinant creation capabilities. The results are robust to different econometric specifications and to a set of robustness checks. An additional set of estimates show a striking geographical divide between Northern and Central–Southern areas, calling attention for future investigation on spatial dynamics behind the greening process in Italy.

We contribute to the recent literature investigating the determinants of regional technological diversification in the green domain (Montresor & Quatraro, 2017; Santoalha & Boschma, 2021) in several ways. First, we exploit the concept of recombinant capabilities extending it to the regional domain, showing their intrinsic geographic dimension. Second, we elaborate on the importance of recombinant dynamics for the entry of regions in new green technological domains, by leveraging the concept of recombinant novelty in inventive activities (Castaldi et al., 2015). This is consistent with recent empirical evidence about the place-based nature of innovation capabilities leading to breakthrough inventions (Lu et al., 2022). Third, we add to the literature on the role of academic inventors in local patenting activities. Based on extant studies highlighting the peculiarities of academic inventors in recombinant dynamics (e.g., Gruber et al., 2013; Melero & Palomeras, 2015) and, specifically, in green invention dynamics (Ocampo-Corrales et al., 2021), our results provide evidence of a positive influence of academic inventors on the entry of regions in new green specializations and of a compensation effect between the local availability of recombinant creation and patenting dynamics involving academic inventors.

As with any study, this one has some limitations that should be mentioned. The first one concerns the use of patent data to measure technological efforts in the green domain as well as university–industry interactions through the involvement of academic scientists in inventive teams. Despite the usual caveats about the fact that new technologies are not always patented, it should be noted that patents have been largely used in the literature investigating determinants and effects of GTs (Barbieri et al., 2016). Importantly, there is common scientific consensus that they are a reliable indicator of the generation of new technologies at the local level (Acs et al., 2002). Furthermore, extant literature has stressed the crucial importance of academic inventors for regional patenting activities (e.g., Lissoni, 2010; Meyer et al., 2003; Murray, 2004). One additional limitation is that the empirical framework does not allow to ascertain neat causal relationships. Yet, our results provide statistically robust as well as interesting associations among the key variables under investigation. Lastly, the availability of information on academic inventors, which limits the time span under investigation up until year 2009, represents a further limitation that calls for further investigation on more recent times.

Yet, our analysis provides insights for further research. First of all, the emphasis on the importance of local capabilities to master recombinant novelty for green technological change opens up the basic question as to how regions with poor capabilities can foster successful R&D efforts in the green domain. This paper points to a possible compensation effect related to the quality of local academic research institutions. Further research should provide additional light on the additional factors that could compensate for the lack of appropriate recombinant capabilities or that could leverage upon the existing but poor endowments. Moreover, and related to the previous point, future research should clarify the role of external funding in the development of capabilities for recombinant novelty in local contexts, with specific attention to the role of public and private investments.

This study also offers relevant messages for policymakers committed to address climate change and environmental issues through the development of local innovation policies in support of research and innovation in the green domain. Besides reaffirming the need to increase the level and chances of developing environmental innovation, our work intends to provide suggestions on how to achieve that objective within a wider local economic development goal. Our work has underscored the key role of regional recombinant capabilities and recombinant novelty in inventive dynamics for green diversification, both individually and jointly considered. Science and technology policies should therefore stimulate boundary spanning research efforts and promote scientific collaborations involving scientists and inventors operating in seemingly unrelated technological domains. Also, regions with poor performances in terms of recombinant novelty could design local innovation policies aiming at triggering cross-regional collaborations with scientists and inventors located in ecosystems characterized by high levels of recombinant novelty, so to stimulate collective learning dynamics.

Importantly, academic inventors turn out to be a key lever because of their direct influence on diversification as well as for their compensation effect in areas scarcely endowed with recombinant capabilities. Therefore, the key implication is twofold. In the first place, it is necessary to recognize the potential of academic contribution to patenting in green domains. Second, policymakers should leverage upon such potential through appropriate instruments and policies. This study points to the argument that policies aiming at pushing regions towards technological diversification in the green domain should also nurture and strengthen the institutional framework that favours successful interactions between industry and university. This is particularly relevant for regions featuring low levels of recombinant novelty. Practically speaking, policies boosting the green transition should go hand in hand with science and technology policies that traditionally stimulate university–industry interactions: in particular, programs that support the involvement of academic inventors in industrial teams of inventors through, for instance, R&D collaboration aimed at the generation of patentable inventions, and academics' industrial secondment schemes, are to be considered.

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NOTES

1. Recombinant reuse refers to the refinement and improvement of existing combinations; recombinant creation refers to the introduction of novel and unexplored combinations (Carnabuci & Operti, 2013).
2. We assume that the average academic inventor is endowed with higher education attainment than the average inventor in industry, on the grounds of the argument that entering academia requires holding a PhD, while this is not necessary for most occupations, including innovation-related ones. This is particularly true in the Italian context where the PhD rate of the working population is relatively low in comparison with other advanced economies, but holding a PhD is compulsory to obtain a tenured academic position.
3. In the data section we document that patents involving academic inventors scores, on average, higher in terms of a number of indicators – including patent scope and generality – compared with patents not involving academics. See section 3.2.2 and Appendix A in the supplemental data online.
4. Green CPC four-digit classes are under the subsection Y02 of the CPC classification. For the complete CPC scheme, see https://www.uspto.gov/web/patents/classification/cpc/html/cpc.html/.
5. We also take three- and five-year windows to check the robustness of the dependent variable (see section 4.2). We thank an anonymous reviewer for suggesting implementing this robustness check.
6. We assign each novel patent to all the regions where its inventors reside. To avoid multiple counting in the case of inventors on the same patent residing in different regions, we assign to regions only the corresponding share of novel patents. Therefore, the measure of recombinant novelty is based on a fractional count.
7. See section 4.2 for a set of robustness checks that concerns the variable *ACAD*.
8. Appendix A in the supplemental data online provides a detailed description of these results.
9. *RTA GREEN* and *RTA GREEN^2* refer to the lagged count of RTAs in GTs that do not consider new RTAs

forming the dependent variable. Therefore, *RTA GREEN* does not overlap with the dependent variable.

10. This is an alternative to the Box–Cox transformations, defined as follows:

$$y = \log\left[y_i + (y_i^2 + 1)^{\frac{1}{2}} \right].$$

The inverse sine can be interpreted as a standard logarithmic variable (except for very small values of y) but it is defined at zero (Johnson, 1949; Burbidge et al., 1988; MacKinnon & Magee, 1990).

11. The variance inflation factor for all models is below the rule of thumb of 10 for all variables, except for the quadratic term *RTA GREEN^2*, as expected.

12. The coefficient of the control variable *R&D PC* is never significant, except for a model where all the other control variables are excluded (the results are available from the authors upon request). This is most likely because *R&D PC* broadly measures the local effort in R&D, without specifically identifying R&D effort for environmental innovation, for which data are not available.

13. We also implemented a spatial Durbin auto-regressive model to investigate spatial effects. In particular, we intend to check whether academic inventors and recombinant novelty from other places (e.g., neighbouring regions) influence the local entry in new green specializations. Besides confirming the main findings of this work, the model does not reveal any tangible spatial effect as the coefficients of the spatially lagged regressors of interest are not statistically significant. The results are available from the authors upon request.

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