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Dipartimento
Economia e Statistica
Cognetti de Martiis

Working Paper Series

19/21

GREEN TECHNOLOGICAL DIVERSIFICATION AND LOCAL RECOMBINANT CAPABILITIES: THE ROLE OF TECHNOLOGICAL NOVELTY AND ACADEMIC INVENTORS

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LEI&BRICK Working Paper 03/2021
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Green technological diversification and local recombinant capabilities:
The role of technological novelty and academic inventors

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Abstract

This paper studies the entry of regions in new green technological specializations, specifically investigating the role of local recombinant capabilities and the involvement of academic inventors in patenting activities, as well as the interplay between the two. We test our hypotheses on a dataset of Italian NUTS 3 regions over the period 1998-2009. The results show that both recombinant capabilities and the presence of academic inventors are positively associated to 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 work are relevant for policy makers involved in the elaboration of successful regional specialization strategies in green technological domains.

Jel Classification Codes: O33; R11

Keywords: green specialization, recombinant novelty, academic inventors

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Introduction

The decoupling of economic growth from environmental degradation has become a major policy concern. In December 2019, the European Commission presented the European Green Deal, a document articulating guidelines and actions to make the EU's economy environmentally sustainable in the long run and to achieve climate neutrality by 2050. More recently, the Member States signed a declaration to accelerate the employment of green digital technologies for the benefit of the environment.[2]

The academic debate has long focused on these issues, stressing that innovation plays a major role in helping firms to adapt to the ongoing process of green transformation and hence to improve their environmental performances. The term eco-innovation encompasses any kind of change, both technological and non-technological, aimed at reducing the environmental risk associated to economic actions (Kemp and Pearson, 2007; Barbieri et al., 2016).

While former investigations of the determinants and effects of eco-innovations have focused on their adoption and generation at the firm-level, more recently a new wave of studies have looked at these issues through the lenses of the geography of eco-innovation. Many authors have stressed the existence of important regional differences in the generation of eco-innovations by local firms, particularly when it comes to green technologies (GTs). Extant literature has started investigating the sources of these differences, as well as of differential patterns of technological specialization in green technologies (see e.g.: Horbach et al., 2012; Ghisetti and Quatraro, 2013 and 2017; Tanner, 2014; Montresor and Quatraro, 2020; Perruchas et al., 2020; Santoalha and Boschma, 2020).

Most of these studies have looked at the role of environmental regulation in influencing cross-regional differences in the generation of eco-innovations. In fact, it is well established that environmental regulation is key to boost investments in eco-innovations as it enables compliance and allows for the joint improvement of economic and environmental performances (Porter and van der Linde, 1995; Rennings, 2000). Another set of studies have framed the discussion within the evolutionary economic geography approach to investigate the extent to which technological *relatedness* drives regional technological specialization in the green domain and which factors likely act as enablers or facilitators that mitigate the effect of cumulativeness and path-dependence (Montresor and Quatraro, 2020). However, little attention has been devoted to the antecedents of GTs, i.e. to the knowledge-related dynamics behind their generation and how these affect regional patterns (see e.g.: del Río Gonzalez, 2009; Quatraro and Scandura, 2019; Orsatti et al., 2020a).

This paper contributes at filling this gap by investigating how the regional capacity to deal with technological novelty, together with the involvement of inventors from the academic community in patenting dynamics, is associated with the intensity of regional entry in new technological

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[2] https://digital-strategy.ec.europa.eu/en/news/eu-countries-commit-leading-green-digital-transformation

specializations in GTs. To do so, we elaborate on the notion of recombinant capabilities (Carnabuci and Operti, 2013) to extend it to the regional domain and introduce the concept of *regional recombinant capabilities*. We develop a theoretical framework combining this approach with the recent literature on the inherent complexity of GTs, claiming that the capacity of regional agents to manage infrequent and unprecedented combination of knowledge inputs is associated with increasing number of entries in new GT specializations (Orsatti et al., 2020a and 2020b; Barbieri et al., 2020). Secondly, we argue that local GT specialization benefits from the involvement of academic inventors, in view of their documented capacity to conduct research spanning technological boundaries (Quatraro and Scandura, 2019). Lastly, we elaborate on the possible interplay between regional recombinant capabilities and the involvement of academic inventors.

The empirical analysis focuses on the emergence of new Related Technology Advantage (RTA) in green technological domains at the Italian NUTS 3 level. Precisely, it exploits a balanced panel of 103 Italian NUTS 3 regions (provinces) observed over the period 1998–2009, blending data from the OECD Regpat, the "Academic Patenting in Europe" (APE-INV) and the Cambridge Econometrics European Regional Database databases.

The rest of the paper is organized as follows. Section 2 elaborates the theoretical framework and spells out the empirical hypotheses. In Section 3 we describe the data sources, the variables and the empirical approach. Section 4 provides the results of the empirical analysis, while Section 5 offers a discussion of the findings and the main conclusions.

1. Literature and Hypotheses

1.1 Regional capabilities and the greening of the economy

Regions show large dissimilarities in their ability to develop new economic activities in general, and new green activities in particular. As a matter of fact, the sustainability literature shows an uneven distribution of green specialisations across regions both in the United States and in Europe (Barbieri and Consoli, 2019; Corradini, 2019; Tanner, 2014, 2016; Santohala and Boschma, 2021). For this reason, it is important to understand what 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 the greening of economies has received only little attention so far (Boschma, 2017; Santohala and Boschma, 2021).

A number of studies applying a relatedness framework find that new green activities are more likely to develop in regions showing a local presence of activities related to green ones. For instance, Tanner

(2016) found strong evidence for the impact of relatedness on the emergence of the new fuel cell industry in European regions, as well as the importance of local access to universities, research activities and user industries (Tanner, 2014, 2016). Van den Berge and Weterings (2014) found that the probability of developing new eco-technologies in European Union regions depends on pre-existing technologies in related fields in the region during the period 1982–2005. Similarly, Montresor and Quatraro (2020) found a positive effect of technological relatedness to local green and non-green knowledge on the emergence of new green specializations in EU-15 regions.

Another set of studies have stressed the relevance of the recombinant knowledge approach in this respect (Zeppini and van Den Bergh, 2011; Quatraro and Scandura, 2019; Orsatti et al. 2020a; Barbieri et al. 2020).[3] The analyses focusing on recombinant dynamics leading to the generation of GTs have identified a number of peculiar aspects that differentiates environmental from non-environmental innovation. For instance, Zeppini and van Den Bergh (2011) propose a model in which the generation of GTs stems from a combinatorial process conducted across different and loosely related areas of the knowledge landscape. This is because combination amongst ‘distant’ technologies is more likely to engender a paradigmatic shift from a dominant non-green regime to a clean technology one (Nightingale, 1998; Fleming, 2001). Patent-level analyses have provided empirical evidence of the higher complexity of GTs, as compared to non-green technologies; in addition, the combinations they rely upon are on average novel ones, i.e. combinations of technological components that had never been tried before (Messeni Petruzzelli et al., 2011; Barbieri et al., 2020).

Collective invention dynamics have been found to be especially important in this domain. The access to external knowledge components loosely related to one another is better managed when the inventive process is carried out by teams involving researchers with heterogeneous backgrounds or specifically endowed with skills allowing for the exploration of wide areas of the knowledge space (Quatraro and Scandura, 2019). Similarly, inventor teams’ recombinant capabilities have proved to be relevant in this context. The concept of recombinant capabilities refers to the ability of individuals to manage novel recombinations (Carnabuci and Operti, 2013).[4] Such ability has been found to be crucial for the successful generation of GTs (Orsatti et al., 2020a). The extension of the recombinant capabilities and collective inventions frameworks to the regional domain provides a interesting setting to address the

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[3] The recombinant approach is rooted in the Schumpeter’s view of innovation as the outcome of an unceasing process of recombination of different knowledge components. The literature aiming at understanding both the mechanisms behind combinatorial activities and the way in which different combinatorial modes affect the outcome of the inventive activity flourished over time (Weitzman 1996 and 1998; Fleming 2001; Fleming and Sorenson 2001). In this direction, the relatedness degree among technological components has been found to be a key factor affecting the success of recombination efforts (Nesta and Saviotti 2005; Nesta 2008; Antonelli et al. 2010; Quatraro 2010 and 2016; Colombelli et al. 2014).

[4] Carnabuci and Operti (2013) distinguish between recombinant creation and recombinant reuse. The former concerns the introduction of novel and unexplored combinations, while the latter is related to the refinement and improvement of existing combinations.

relationship between novelty and the greening of the economic from an economic geography viewpoint. In the next sections, both frameworks will be discussed in details.

1.2 The role of regional *recombinant* capabilities

Regional innovation capabilities refer to the ability of local agents and institutions to command and coordinate systemic interactions for the production of new knowledge (Foss, 1996; Lawson and Lorenz, 1999; Romijn and Albu, 2002). Such capabilities emerge over time from the development of innovation activities within economic systems and from learning dynamics that enhance local agents' capacity to combine external and internal inputs (Quatraro, 2009).

The appreciation of the recombinant dynamics behind the generation of innovations calls for the refinement of this framework to introduce the concept of *regional recombinant capabilities*. These refer to the capacity of local innovation ecosystems to activate combinatorial processes aiming at the introduction of novelties. According to an established tenet in the literature, regional innovation systems are characterized by the presence of a variety of institutional actors: importantly, the networks of interactions among them are key to trigger innovation dynamics relying on learning processes that lead to the accumulation of knowledge, skills and capabilities (Cooke, 2001). Therefore, understanding the generation of new technologies at the regional level entails recognising the extent to which localized learning dynamics and systemic interactions can activate new and unique combinations rather than refinement and improvement of already known combinations.

The extension of the distinction between recombinant reuse and recombinant creation capabilities to the regional domain provides a fruitful setting to appreciate and qualify the dynamics behind new paths creation at the local level (Martin and Sunley, 2006). Accordingly, transplantation may not necessarily occur by importing knowledge from other geographical areas, but also from other areas of the knowledge space. Indeed, the capacity to connect knowledge components never combined before, i.e. recombinant creation, is a kind of transplantation in this respect.

New specialisations in GTs are highly likely to emerge out of recombinant creation dynamics, hence they are the outcome of an effort to open up new regional technological paths. Therefore, recent efforts to characterize regional knowledge production in terms of the degree of novelty are relevant in this respect. In particular, a growing body of the geography of innovation literature has started investigating the determinants of regional differences in the production of pure novelties, or technological breakthroughs, and how these correlate to key geographical dimensions such as city size (Castaldi et al., 2015; Mewes, 2019). These studies identify regional novelty by looking at the co-occurences of technological classes within patent documents issued in the region. It has been found that recombinant novelty, i.e. the appearance of patents showing *atypical* combinations, is associated to knowledge bases characterized by relatively high levels of unrelated variety, and it is more likely to occur in very large cities.

The generation of new GTs in local innovation systems is thus not only influenced by the heterogeneity of local knowledge bases but also, and most importantly, by the local availability of competences allowing for the combination of knowledge inputs that are both highly dispersed across the knowledge space and loosely related. The concept of capabilities itself implies a process of historical accumulation through experimentation and learning. However, the increasing pressure to improve the environmental performances of economic activities, and the consequent increased stringency of regulatory frameworks, has engendered a sheer increase in the demand for GTs, making their production a business more and more profitable (Colombelli et al., 2020). Areas with little or no recombinant creation capabilities, where agents are more familiar with the refinement or improvement of known combinations, are likely to be worse off in this context. On the contrary, the presence of recombinant creation capabilities within a region provides a fertile ground to conduct research aiming at generating new technologies for the reduction of environmental risk.

In view of these arguments, we postulate that higher levels of recombinant capabilities inside regions lead to higher amounts of new green specialisations, and we put forward the first hypothesis of this work as follows:

Hyothesis 1: the amount of new green specialisations developed inside regions is positively related to the level of local recombinant creation capabilities.

1.3 The role of academic inventors

The development of environmental innovation requires a substantial recourse to external knowledge from a wide variety of organisations (see e.g. Cainelli et al., 2012; Cainelli et al., 2015; De Marchi, 2012). Besides partners belonging to the supply chain, other relevant agents such as competitors, knowledge intensive business services and research institutions are important to nurture the knowledge base of the firm (De Marchi and Grandinetti, 2013). The relevance of external knowledge for environmental innovation is due to the intrinsic higher complexity and higher novelty of green innovation. Green innovations are complex primarily because resulting from the combination and integration of various new and heterogeneous technologies and knowledge components (Orsatti et al., 2020a, Messeni Petruzzelli et al., 2011).[5] Similarly to all complex technologies, green innovations are associated with knowledge that is sophisticated and difficult to understand. The technological novelty of green innovations positively depends upon the distance from the previous technological paradigm. In

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[5] An additional source of complexity derives from the same high complexity of environmental issues and the many ways these can be tackled (Messeni Petruzzelli et al., 2011).

fact, green technological innovation has been proved to be a major source of change with respect to previous paradigms (Azzone and Noci, 1998), while at the same time being characterised by high market uncertainty. Complexity and novelty of GTs involve a great deal of complex tasks to be performed and require information and skills often distant from the industry knowledge base (Messeni Petruzelli et al., 2011; De Marchi, 2012).[6]

The features of GTs introduced above, together with the relevance of recombinant creation capabilities, bring the key role of collective invention dynamics at the core of the discussion. The collaboration among different organizations that are repositories of a variety of specialist knowledge and competences has indeed proven to be a fruitful organizational mode for the generation of GTs (De Marchi, 2012; De Marchi and Grandinetti, 2012). In particular, recent contributions have stressed that collaboration with universities is a primary source of comparative advantage in doing research in the green domain, as it is essential for achieving more radical innovation and relative novel technologies (Cainelli et al., 2012; Triguero et al., 2013; Fabrizi et al., 2018).

Cainelli et al. (2012) show that networking and cooperation with universities are essential for achieving more radical and relatively new innovations such as environmental ones. Similarly, De Marchi and Grandinetti (2013) show that GTs are more sensitive to collaborations with universities and research centres, with respect to standard innovation. At European level, Triguero et al. (2013) find that small and medium firms interacting with institutional agents, including research institutes, agencies and universities, perform better in terms of green patents. On the same vein, a recent study by Fabrizi et al. (2018) investigating the role of regulatory policies and research networks for environmental innovation across European countries, confirms that the contribution of universities and public research centers in green research networks is positive and higher than the contribution of private firms. These studies point to and confirm the arguments that specialisations in GTs need a large set of competences and skills and, therefore, collaboration with 'high profile' agents that possess those assets are fundamental to the successful generation of environmental innovation. Such argument relies on the well-acknowledged and documented stylised fact that universities have a pivotal role for innovation activities of firms and, more generally, for technological progress and economic development (see e.g. Griliches, 1987; Jaffe, 1989; Adams, 1990; Dasgupta and David, 1994).

Micro-level studies have shown that the educational attainment of inventors is a key driver of success for collaboration and teamwork knowledge production, especially in science and engineering (Allen

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[6] Empirically, while investigating the determinants of EPO green patents at inventor team level, Orsatti et al. (2016) show that experimentation with unexplored knowledge components is more likely to drive the emergence of green inventions, with respect to refinement and improvement of known components. Similarly, analysing green patents developed by firms included in the Dow Jones Sustainability World Index 2004, Messeni Petruzzelli et al. (2011) find that the technologies underling green inventions are characterized by a higher degree of complexity and novelty, which they measure by counting patent classes to which a patent is assigned and patent classes in which previous patents cited by the given patent are found, respectively.

1984). An extensive literature has shown that inventors with higher educational achievement are more likely to better address technological problem solving; in addition, they are less likely to be locked-in by cognitive constraints and more inclined to engage in boundary-spanning activities (March and Simon 1958; Hambrick and Mason 1984; Gagné and Glaser 1987; Walsh 1995; Pelled 1996; Hargadon 2006). Gruber et al. (2013) have shown that patents spanning technological boundaries are more likely to be produced by scientists than engineers, concluding that inventors holding a scientific background are better able to command recombinant dynamics across different and unrelated technological domains. On a similar vein, Quatraro and Scandura (2019) argue that, as compared to inventors employed in industry, academic inventors are expected to hold the necessary capabilities to recombine knowledge across diverse technological domains, this being a fundamental pre-condition for the creation of environmentally sound inventions.

Based on this conceptual background, we hypothesise that the involvement of inventors from university in patenting activity bears positive influence on the capacity of local innovation systems to enter new green technological specializations. First of all, the involvement of academic inventors is a means for firms to develop cooperation with external agents so to access specialist knowledge that is necessary to successfully introduce environmental innovation. Secondly, provided the level of cumulated human capital required to access academic positions, it can be assumed that academic inventors have on average a higher level of education than those employed in industry; and higher levels of education are associated with higher abilities and willingness to recombine knowledge across a wide array of technological domains. Accordingly, we posit that the development of collaborations between university and industry throughout the involvement of academic inventors represents a fruitful strategy to increase the likelihood for regional innovation systems to improve their diversification in green technological domains.

As discussed above, the presence and 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 with respect to areas well-endowed with such kind of combinatorial competences. Academic inventors, in view of their intrinsic capacity to carry out boundary-spanning research, can be expected to compensate for the absence of recombinant creation capabilities in local contexts. While the latter require time to be developed and strengthened, partnerships between academic institutions and other key agents of the innovation ecosystem may be promoted in a more timely manner. This would lead to an additional impact of the involvement of academic inventors in local innovation dynamics on the entry in 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 green technologies 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 impact of academic inventors on the entry in new green technological specializations:

Hypothesis 2a: the amount of new green specialisations developed inside regions is positively associated to the involvement of academic inventors in patenting activity.

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

2. Data, variables and methodology

2.1 Data sources

We test our hypotheses on a balanced panel dataset of 103 Italian NUTS 3 regions (i.e. Italian provinces) observed from 1998 to 2009. Data sources are multiple. First, we collect patent information from the OECD Regpat database, which allows assigning patents to Italian provinces by exploiting information contained in recorded inventor addresses. Second, we rely on the "Academic Patenting in Europe" (APE-INV) database to individuate Italian academic inventors. Third, we collect regional administrative data from the Cambridge Econometrics European Regional Database. Additional data come from a well-established and recognised Italian environmental no profit association called Legambiente.

2.2 Variables

2.2.1 Dependent variable

Following previous studies on regional innovative specialization (e.g. Boschma et al, 2013; Colombelli et al., 2014; Montresor and Quatraro, 2017), our main dependent variable is the count of entries in new green technological specializations of region i at time t. Precisely, to build our dependent variable we count the number of acquisitions of green specializations 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 for trade specialization, redefined in terms of number of patents filed in the green IPC classes (Revealed Technological Advantages, RTAs). In our preferred specification, we take a 6-year window interval to build our measure of regional entry in new green specializations.

To individuate green patent IPC classes and build measures of green RTAs, we exploit the OECD Indicator of Environmental Technologies (OECD, 2011) combined with the OECD Regpat database (Maraut et al., 2008). The OECD Indicator of Environmental Technologies, based on the International Patent Classification (IPC), individuates seven broad environmental areas: (a) general environmental management, (b) energy generation from renewable and non-fossil sources, (c) combustion technologies with mitigation potential, (d) technologies specific to climate change mitigation, (e) technologies with potential or indirect contribution to emission mitigation, (f) emission abatement and fuel efficiency in transportation, and (g) energy efficiency in buildings and lighting. The OECD Regpat database provides direct links between IPC classes and regions according to the addresses of the inventors listed in patent documents.

2.2.2 Independent variables

We focus on two main explanatory variables: (i) the number of patents invented in the region showing novel recombination and (ii) the involvement of academic inventors in local patenting activities.

To measure combinatorial novelty we rely on the co-occurrence of patent IPC classes between citing and cited patents. The rationale for exploiting links between patents and their citations to measure novelty is that patent citations are references to prior technology on which the current patent builds on, i.e. prior art (Trajtenberg, 1990; Jaffe et al., 1993; Jaffe and Trajtenberg, 1999; Maurseth and Verspagen, 2002). Therefore, if the technology classifying the patent relies on a novel bit of prior art, this signals for an original occurred combinatorial attempt that, likely, deepens the local technology space favoring new trajectories (Fleming, 2001). We define as novel in recombination a patent that links, for the first time in Italy, a specific IPC class with another IPC (contained in the patent backward citations). We borrow this measure from Verhoeven et al. (2016) and we adapt it to the Italian context. Therefore, a patent filed in year t shows a novel combination if the same combination was never observed before within patents filed by inventors resident in Italy. Since we are interested in the relationship between local combinatorial novelty in non-green domains and regional entry in new green specializations, we do not consider green IPC classes when measuring combinatorial novelty. To assign novel patents to Italian provinces, we rely on information contained in inventor addresses reported in the OECD Regpat database.

>>> INSERT TABLE 1 ABOUT HERE <<<

We then focus on the involvement of academic inventors in local patenting activity. We retrieve information on academic inventors from the APE-INV database. The database collects information on patents filed by academics at the EPO. We restrict the sample to Italian academic inventors (i.e. inventors residing in Italy and working in Italian academic institutions). Accordingly, we assign academic patents to provinces and we build an indicator that takes value 1 for provinces with at least one patent filed by an academic inventor, and 0 otherwise ($ACAD$). In our sample, 47% of provinces across time (1998-2009) presents academic patenting activity (see Table 1).

2.3 Econometric model

The estimated baseline model takes the following form:

$$Y_{i,t} = \alpha + \beta_1 ACAD_{i,t-1} + \beta_2 RC_{i,t-1} + \beta_3 ACAD_{i,t-1} \times RC_{i,t-1} + \boldsymbol{X}_{i,t-1}\boldsymbol{\psi}' + \gamma_r + \phi_t + \varepsilon_{i,t}$$

Where $Y_{i,t}$ is the count of entries in new green specializations of region i at time t (taking a 6-year window interval). $ACAD_{i,t-1}$ is a dummy indicator for the involvement of academic inventors in region i at time $t-1$. $RC_{i,t-1}$ is the proxy for local recombinant creation capabilities, i.e. the number of patents invented in region i at time $t-1$ showing novel recombination (i.e. patent IPC linked to cited IPC for the first time). β_3 captures the effect of the interaction between the presence of academic inventors and the count of novel patents. Following previous literature, in the baseline specification, $\boldsymbol{X}_{i,t-1}$ is a vector of the following control variables: i) the number of revealed green technology advantages ($RTA\ GREEN$), ii) the square of the number of revealed green technology advantages ($RTA\ GREEN^\wedge 2$), iii) the density (relatedness) of green technologies ($DENS\ GREEN$), iv) the density (relatedness) of non-green technologies ($DENS\ NON-GREEN$), v) GDP per capita ($GDP\ PC$), vi) R&D per capita ($R\&D\ PC$). γ_r and ϕ_t are regional NUTS-2 and year fixed effects, respectively. We cluster standard errors at the NUTS-3 level. In augmented versions of the main empirical specification, we also control for the local environmental policy stringency, proxied by the index of urban environmental quality proposed by the Italian non-profit organization Legambiente. The Legambiente's index evaluates and ranks the 103 province-capital cities in Italy, based on several indicators of e.g. air quality, green areas, drinking water quality, energy consumption, and waste recycling performance. This ranking provides an implicit assessment of the performance of local policy-makers in managing environmental protection tasks (Bianchini and Revelli, 2013). According to this index, we build an indicator of environmental policy stringency ($ENVIRON_{i,t,}$) that takes value one if the province is above the national annual median, zero otherwise. The Legambiente's index is available since 2001 and, consequently, the number of observations reduces when we add this further control variable.

In the main analysis, we use OLS estimators and we transform the dependent variable and the continuous control variables applying the inverse hyperbolic sine transformation (IHS). In robustness checks, we use also negative binomial estimators.

3. Results

3.1 Main results

Results from the baseline analysis are reported in Table 2. Columns I and III report the results without considering the interaction term $ACAD \times RC$. The two models differ because, in column III, we add the indicator of environmental policy stringency ($ENVIRON$) as a further control to the specification reported in column I. The variable RC shows a positive and statistically significant coefficient in both specifications. Precisely, a 1% increase in the number of local patents showing novel recombination leads to an increase in the number of entries in new green specializations that ranges between ~6.5% (column III) and ~8.1% (column I). These results provide support to our first hypothesis.

We then turn to the expected positive role of academic patenting, looking at the variable $ACAD$. Precisely, provinces where academics are actively involved in patenting activities show, on average, between ~11.3% (column I) and 14.1% (column III) more new green technological specializations. This corroborates our hypothesis 2a.

>>> INSERT TABLE 2 ABOUT HERE <<<

In columns II and IV we add the interaction term $ACAD \times RC$ to the specification. The coefficients for this interaction term are negative and statistically significant in both cases. This would suggest that, on average, the impact of academic inventors on the entry in green specializations marginally decreases when regions are more endowed with recombinant creation capabilities. In other words, as discussed in Section 2, the importance of academics is expected to increase when regions lack recombinant creation capabilities. In these cases, the presence of academic inventors might be, in fact, a relevant enabling diver for regions to specialize in new green technologies even if their endowment of recombinant capabilities is poor.

Figure 1 provides a graphical representation of this result. It 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, provinces where academic inventors are involved in patenting activity display higher predicted levels of entry in new green specializations than provinces where there are zero academic patents. In other words, the average marginal contribution of academic inventors to the regional entry in new green specialization is positive and significant up to a relatively high level of RC. Above the third quartile of RC, however, this average marginal contribution disappears (i.e. when regions show the highest levels of RC, whether academics are involved or not in patenting activities does not significantly influence the regional outcome in terms of number of entries in new green specializations). This implies that the involvement of academics in innovation activities may compensate for the lack of appropriate levels of local recombinant creation capabilities.

Figure 2 helps in better appreciating the average marginal contribution of academics to the number of regional entry in new green specialization. It directly plots the average marginal effects (AMEs) of the dummy $ACAD$ for different levels of RC. Precisely, it plots AMEs at, respectively, the first quartile, median, mean, third quartile and ninth decile of RC. The average marginal effect of $ACAD$ diminishes when regions show higher levels of RC, as evident also from Figure 1, reaching no significant effect when regions are positioned at the third quartile of the distribution of RC or above.

In all, this evidence corroborates our 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.

>>> INSERT FIGURES 1 AND 2 ABOUT HERE <<<

With respect to the set of control variables, we estimate positive and significant coefficients for $GDP\ PC$, $RTA\ GREEN$ in columns I and II, $DENS\ GREEN$ in columns I to III.

4. Conclusions

This work has investigated the entry of regions in new green technological specialisations, specifically focusing on the relationship with the level of regional recombinant creation capabilities and the involvement of university inventors in local patenting activity. We developed a theoretical framework grounded on the recombinant knowledge approach and its recent application to the analysis of the antecedents of green technologies. In this framework, theoretical and empirical studies have stressed that GTs are on average more complex than non-green technologies and that patenting activities in the green domain are favoured by the capacity to combine technologies that are loosely related to one another (Zeppini et al., 2011; Barbieri et al., 2020; Orsatti et al., 2020a). Accordingly, we have hypothesized that the local accumulation of innovation capabilities based on the implementation of atypical and unprecedented combination of knowledge components is crucial for the success of innovation dynamics in the green domain. On similar grounds, we have followed the stream of literature on university-industry collaboration that stresses the advantages of involving scientists from academic institutions in inventor teams (Baba et al., 2009). These advantages are related to the educational attainment of academic inventors and the related higher likelihood to be able to command boundary-spanning exploratory research leading to combinations of knowledge components from dispersed areas of the knowledge space (Quatraro and Scandura, 2019). Furthermore, we consider and investigate the interplay between academic inventors and recombinant creation capabilities, hypothesising that the former may 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 empirical analysis has focused on the entry in new green specialisations in Italian NUTS 3 regions, over the period 1998-2009. Our results provide evidence of empirical associations between the level of new green specialisations and both the extent of local recombinant creation capabilities and the involvement of academic inventors. The data also supports the hypothesis concerning the compensation effect of academic inventors in areas scarcely endowed with recombinant creation capabilities. The results are robust to different econometric specifications.

As any empirical study, this one is not free from limitations, mostly related to the exploitation of patent data (and their IPCs) to proxy for technological efforts in the green domains and to the measurement of university-industry interactions through the involvement of academic researchers in inventor teams. As for the former issue, while it is well-known that new invented technologies are not always patented, it should be noted that, despite their limitations, patents have been extensively used in the literature dealing with eco-innovation dynamics (Barbieri et al. 2016) and there is large scientific agreement that they are a reliable indicator of the generation of new technologies, notably at the local level (Acs et al. 2002). Secondly, extant literature has stressed the crucial importance of academic inventors for regional patenting activities (see e.g. Meyer et al. 2003; Murray 2004; Lissoni 2010). Lastly, our empirical framework does not allow us to ascertain causal relationships. Therefore, while showing strong statistical associations, our results must be interpreted with caution.

Yet, this paper contributes to the literature attempting to open the black box of green technological specialisations as it unveils knowledge dynamics and related innovation capabilities behind their development. Firstly, we contribute to the literature on the regional antecedents of green specialisations, by elaborating upon the role of recombinant capabilities. Secondly and relatedly, we make a step forward in the consideration of recombinant dynamics behind the entry in new green areas, by leveraging the concept of novelty in the combination of knowledge components to invent new technologies (Castaldi et al. 2015). Thirdly, we add to the literature on the role of academic inventors in local patent dynamics. Drawing upon the literature stressing the peculiarities of inventors in recombination dynamics (e.g. Gruber et al. 2013), we show that there are compensation effects between the accumulation of recombinant creation capabilities at the local level and the involvement of academic inventors in patenting activities.

Our results bear interesting policy implications for the elaboration of successful regional strategies to promote research and innovation in the green domain, in view of the increasing commitment at the European level to cope with climate change and achieve decarbonized societies. Environmental innovations in general and green technologies in particular represent a key lever that will allow to comply with the objectives of the European Green Deal, as well as their articulation at the regional level in EU Cohesion Policies. Regions characterized by a well-established innovation system specialized in research and innovation activities dealing with complex technologies and based on exploration dynamics will be better off in this respect. However, strengthening the institutional framework conducive to successful collaborations between industry and universities might be a complementary strategy for regions that show innovation dynamics mostly focused on incremental improvements of known technologies, having scarce impact on the advancement of the knowledge frontier.

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Table 1. Descriptive statistics and variables definition

Variable	Description	Obs	Mean	S.D.	Min	Max
GREEN SPEC ENTRY *	Log-transformed number of regional entries in new green specialization (6y window).	1133	0.85	1.05	0	5.00
RC *	Log-transformed number of patents with a novel recombination invented in the region.	1133	1.13	1.15	0	4.71
ACAD **	Dummy = 1 if at least one academic patent invented in the region.	1133	0.48	0.50	0	1.00
RTA GREEN *	Log-transformed number of revealed technology advantages in green IPC classes.	1133	0.74	0.75	0	2.64
DENS GREEN *	Technological relatedness (density) to green RTAs.	1133	0.04	0.10	0	0.72
DENS NON-GREEN *	Technological relatedness (density) to non-green RTAs.	1133	0.08	0.15	0	1.12
GDP PC ***	Log-transformed level of regional GDP per capita.	1133	3.80	0.27	3.14	4.33
R&D PC ***	Log-transformed level of regional R&D expenditures per capita.	1133	13.80	0.50	11.97	14.70
ENVIRON ****	Dummy indicator = 1 if region's value of Legambiente index is above the national yearly median	927	0.49	0.50	0	1
YEAR FIXED EFFECTS	-	-	-	-	-	-
NUTS2 FIXED EFFECTS	-	-	-	-	-	-

Data sources: * APE-INV Database, ** OECD RegPat Database, * Cambridge Econometrics, **** Legambiente index of urban environmental quality (available since 2001)**

Table 2. Baseline regressions (OLS)

	(I)	(II)	(III)	(IV)
RC	0.081^{**}	0.148^{***}	0.065^{**}	0.123^{**}
	(0.029)	(0.039)	(0.032)	(0.043)
ACAD	0.113^{**}	0.230^{***}	0.141^{**}	0.240^{***}
	(0.051)	(0.061)	(0.055)	(0.067)
RCxACAD		-0.106^{**}		-0.091^{**}
		(0.042)		(0.045)
RTA GREEN	0.170^{**}	0.141^{*}	0.140	0.112
	(0.084)	(0.080)	(0.085)	(0.083)
RTA GREEN^2	-0.047	-0.034	-0.037	-0.024
	(0.045)	(0.043)	(0.047)	(0.046)
DENS GREEN	0.472^{**}	0.433^{**}	0.386^{*}	0.340
	(0.214)	(0.215)	(0.232)	(0.237)
DENS NON-GREEN	-0.108	-0.059	0.090	0.120
	(0.216)	(0.220)	(0.236)	(0.239)
GDP PC	0.653^{**}	0.651^{**}	0.585^{**}	0.603^{**}
	(0.220)	(0.222)	(0.257)	(0.258)
R&D PC	-0.169	-0.176	-0.159	-0.164
	(0.138)	(0.139)	(0.194)	(0.193)
ENVIRON			0.076	0.015
			(0.427)	(0.417)
N	1133	1133	927	927
R^2	0.251	0.257	0.243	0.247

Dep. Var.: **entry in new green specializations** (IHS-transformed).
Clustered standard errors in parentheses. * $p < .1$, ** $p < .05$, *** $p < .001$
Fixed effects: **YEAR** and **NUTS2** (all columns)

Figure 1. Adjusted Predictions of ACAD with 95% CIs

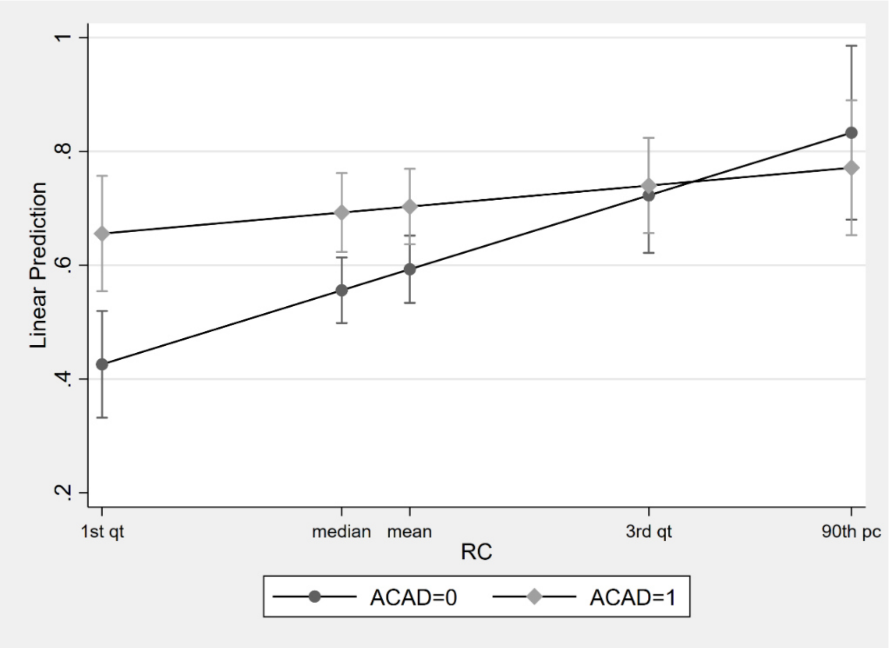
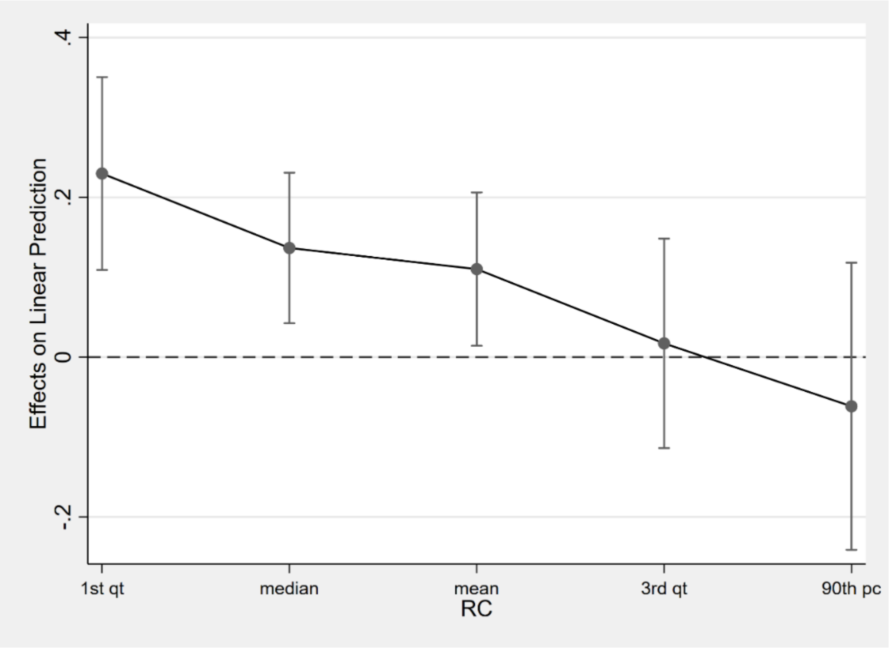


Figure 2. Average Marginal Effects of 1.ACAD with 95% CIs



APPENDIX A - Additional analyses and robustness checks

We carry out a set of additional regressions aimed at providing further results as well as at corroborating the main ones. In the first place, we split the sample into northern and central-southern regions and replicate the analysis performed in Table 2 in the main text. The split follows the distribution of green technologies across time as shown in Quatraro and Scandura (2019). Northern regions include provinces of Piedmont, Valle d'Aosta, Liguria, Lombardy, Veneto, Friuli-Venezia Giulia, Emilia-Romagna and Autonomous provinces of Trento and Bolzano; Central and Southern regions are those in Tuscany, Marche, Umbria, Lazio, Abruzzo, Molise, Puglia, Campania, Basilicata, Calabria, Sicilia and Sardegna. Table A1 shows that the empirical hypotheses are fully confirmed in the sample of norther regions only, while only academic inventors seem to play a role in the greening process inside central-southern regions. The latter is an interesting result showing 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.

In the second place, we replicate the regressions reported in Table 2 in the main text by using a negative binomial estimator. In this case, we consider the dependent variable (i.e. entry in new green specializations) as a count variable. Table A2 shows that the results of the baseline analysis are confirmed and robust to different estimators.

Finally, we perform the split sample analysis as in Table A1 using a negative binomial model. Table A3 confirms the main findings, showing that academic inventors play a positive role in both north and central-southern provinces, while recombinant capabilities represent a lever of green specialization mainly for northern regions.

Table A1. Heterogeneity 1: North vs South (OLS)

	North (I)	North (II)	South (I)	South (II)
RC	0.200^{***}	0.192^{**}	0.040	0.006
	(0.049)	(0.059)	(0.065)	(0.062)
ACAD	0.316^{**}	0.360^{**}	0.153^{**}	0.159^{*}
	(0.129)	(0.141)	(0.076)	(0.081)
RCxACAD	-0.175^{**}	-0.175^{**}	0.068	0.078
	(0.061)	(0.068)	(0.082)	(0.076)
RTA GREEN	-0.010	0.013	0.309^{**}	0.257^{**}
	(0.137)	(0.149)	(0.099)	(0.104)
RTA GREEN^2	0.056	0.055	-0.164^{**}	-0.160^{**}
	(0.063)	(0.068)	(0.068)	(0.074)
DENS GREEN	0.406	0.156	0.413	0.653^{*}
	(0.282)	(0.304)	(0.317)	(0.347)
DENS NON-GREEN	-0.257	-0.112	0.524	0.651
	(0.263)	(0.295)	(0.483)	(0.509)
GDP PC	0.505	0.302	0.681^{**}	0.774^{**}
	(0.421)	(0.498)	(0.261)	(0.273)
R&D PC	-0.166	0.024	-0.183	-0.265
	(0.199)	(0.292)	(0.204)	(0.266)
ENVIRON		0.082		-0.103
		(0.769)		(0.435)
N	506	414	627	513
R^2	0.177	0.175	0.265	0.255

Dep. Var.: **entry in new green specializations** (IHS-transformed).
Clustered tandard errors in parentheses. $^{*}p < .1$, $^{**}p < .05$, $^{***}p < .001$
Fixed effects: **YEAR** and **NUTS2** (all columns)

Table A2. Baseline (Negative Binomial)

	(I)	(II)	(III)	(IV)
RC	0.093^{**}	0.276^{***}	0.067	0.222^{**}
	(0.047)	(0.072)	(0.050)	(0.074)
ACAD	0.212^{**}	0.599^{***}	0.251^{**}	0.557^{***}
	(0.096)	(0.138)	(0.097)	(0.141)
RCxACAD		-0.274^{***}		-0.226^{**}
		(0.070)		(0.071)
RTA GREEN	0.525^{***}	0.435^{**}	0.453^{**}	0.376^{**}
	(0.157)	(0.149)	(0.158)	(0.152)
RTA GREEN^2	-0.172^{**}	-0.135^{*}	-0.149^{**}	-0.117
	(0.073)	(0.070)	(0.074)	(0.073)
DENS GREEN	0.671^{**}	0.529^{*}	0.574^{*}	0.437
	(0.281)	(0.283)	(0.301)	(0.307)
DENS NON-GREEN	-0.394	-0.331	-0.105	-0.074
	(0.269)	(0.280)	(0.292)	(0.299)
GDP PC	1.348^{**}	1.498^{**}	1.163^{**}	1.305^{**}
	(0.502)	(0.486)	(0.529)	(0.520)
R&D PC	-0.361	-0.380	-0.309	-0.315
	(0.301)	(0.298)	(0.394)	(0.388)
ENVIRON			0.379	0.246
			(0.855)	(0.831)
N	1133	1133	927	927

Dep. Var.: **entry in new green specializations** (count variable).
Clustered standard errors in parentheses. $^{*}p < .1$, $^{**}p < .05$, $^{***}p < .001$
Fixed effects: **YEAR** and **NUTS2** (all columns)

Table A3. Heterogeneity 1: North vs South (Negative Binomial)

	North	North	South	South
	(NB)	(NB)	(NB)	(NB)
RC	0.283**	0.258**	0.171	0.053
	(0.088)	(0.096)	(0.163)	(0.155)
ACAD	0.525**	0.544**	0.525**	0.470**
	(0.223)	(0.233)	(0.204)	(0.198)
RCxACAD	-0.266**	-0.252**	-0.066	0.019
	(0.097)	(0.101)	(0.188)	(0.170)
RTA GREEN	0.129	0.145	0.841***	0.734***
	(0.208)	(0.225)	(0.209)	(0.206)
RTA GREEN^2	0.019	0.019	-0.412***	-0.397**
	(0.090)	(0.094)	(0.122)	(0.130)
DENS GREEN	0.467	0.180	0.595	0.976*
	(0.335)	(0.335)	(0.501)	(0.525)
DENS NON-GREEN	-0.429	-0.247	0.482	0.828
	(0.318)	(0.345)	(0.715)	(0.716)
GDP PC	0.725	0.461	2.067**	1.977**
	(0.601)	(0.666)	(0.735)	(0.719)
R&D PC	-0.373	-0.037	-0.388	-0.487
	(0.352)	(0.490)	(0.548)	(0.636)
ENVIRON		0.121		-0.209
		(1.171)		(1.263)
N	506	414	627	513

Dep. Var.: **entry in new green specializations** (count variable).
Clustered standard errors in parentheses. * $p < .1$, ** $p < .05$, *** $p < .001$
Fixed effects: **YEAR** and **NUTS2** (all columns)

Figure A1. Adjusted Predictions of ACAD with 95% Cis (North)

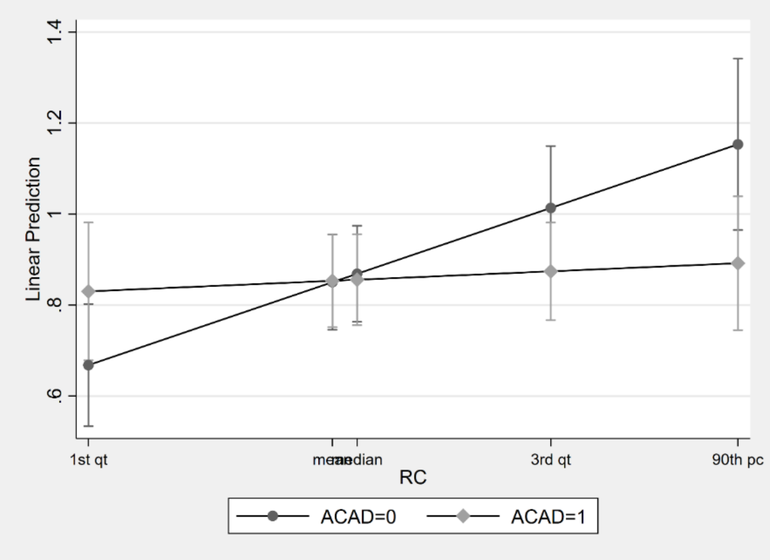


Figure A2. Average Marginal Effects of 1. ACAD with 95% Cis (North)

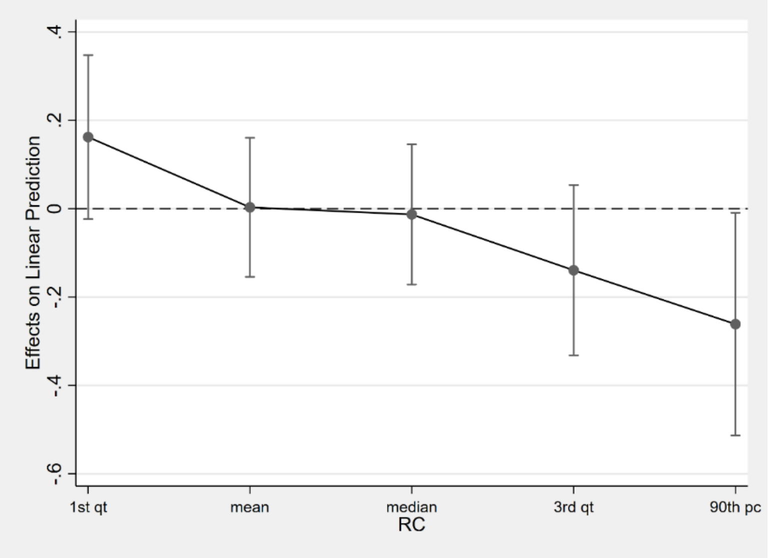


Figure A3. Adjusted Predictions of ACAD with 95% Cis (South)

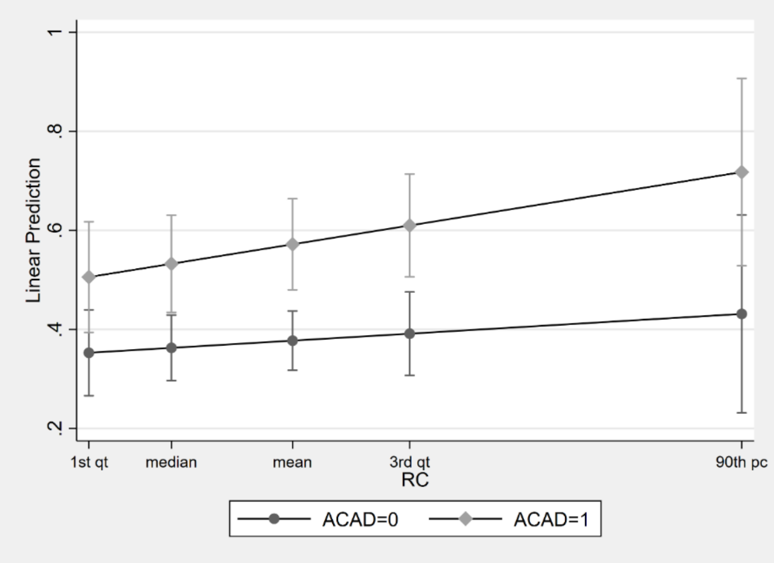


Figure A4. Average Marginal Effects of 1.ACAD with 95% Cis (South)