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INSTITUTIONAL QUALITY AND GREEN INNOVATION IN ITALY: A REGIONAL PERSPECTIVE

Adriana Carolina Pinate
Martina Dal Molin
Maria Giovanna Brandano

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CRENoS – CAGLIARI
VIA SAN GIORGIO 12, I-09124 CAGLIARI, ITALIA
TEL. +39-070-6756397

CRENoS - SASSARI
VIA MURONI 25, I-07100 SASSARI, ITALIA
TEL. +39-079-213511

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Viale Bonaria 98 - 09125 Cagliari
Tel. 070/6848663 - info@arkadiaeditore.it
www.arkadiaeditore.it

Institutional Quality and Green Innovation in Italy: A Regional Perspective

Adriana Carolina Pinate
Gran Sasso Science Institute, Italy

Martina Dal Molin
Vilnius University, Faculty of Economics and Business Administration, Lithuania

Maria Giovanna Brandano*
Gran Sasso Science Institute & CRENoS, Italy

Abstract

This paper analyses the relationship between institutional quality and green innovation in Italian regions (NUTS2). We examine how varying levels of institutional quality influence the regional capacity to generate green innovation, disentangling the effects related to economic institutions (corruption, government effectiveness, and regulatory quality) from the impacts associated with political institutions (rule of law and voice and accountability). Using a panel of data for 2004–2018 on green patents, we use an instrumental variable IV approach to control for endogeneity and several robustness checks. Our results show that the most important drivers of green innovation are related to the quality of political institutions. These findings remain robust, even when checking for economic and environmental controls, demonstrating that green innovation is more related to political decisions and social capital than innovation in general is.

Keywords: regional green innovation, green patents, Institutional Quality, Italy
Jel Classifications: H11, O31, O34, R11.

* Corresponding author. E-mail: mariagiovanna.brandano@gssi.it

1. Introduction

Innovation has long been recognized as a driver of regional and national economic development (Wu et al., 2021; Lundvall, 1992) while also enhancing firms' competitive advantage through cost reductions and improved performance (Chen et al., 2021; Wu et al., 2021; Horbach and Jacob, 2018). In recent years, especially following the 2012 Rio+20 Conference on Sustainable Development, policymakers and scholars have shifted their focus from general innovation to innovations that foster a sustainable society and address climate change (Häggmark and Elofsson, 2022; Buesa et al., 2010). This shift is commonly associated with "green" (Takalo and Tooranloo, 2021; Amore and Bennedsen, 2016) or "environmental" innovations (Horbach, 2008; Del Brío and Junquera, 2003). Accordingly, green innovation has come to play a central role in promoting environmental sustainability and economic growth (Galliano et al., 2023; Losacker et al., 2023a; Sheng and Ding, 2023; Wang et al., 2021; Mazzanti, 2018; Antonioli et al., 2016). At a general level, green innovation is defined as a new technological paradigm involving the creation of novel concepts, products, services, procedures, and managerial frameworks that adhere to ecological principles and prevent, eliminate, or mitigate environmental problems (Favot et al., 2023; Galliano et al., 2023; Zhou et al., 2021; Antonioli et al., 2016; Kemp, 2010; Rennings, 2000). Scholars have investigated green innovation from various perspectives, including technology push and market pull factors (Montresor and Quatraro, 2020; Zhang et al., 2019), path development (Trippl et al., 2020; Grillitsch and Hansen, 2019), and the effects of green innovation on both sustainability transitions (Rohe and Chlebna, 2021) and firm performance (Antonietti and Cainelli, 2011).

However, three important aspects have been mainly overlooked in this growing literature. Firstly, the regional perspective has been largely neglected, despite regions being the primary environments where green innovations are developed, which in turn fosters regional development (Galliano et al., 2023; Losacker et al., 2023a; 2023b; Montresor and Quatraro, 2020; Antonioli et al., 2016; Sun et al., 2020; Belik et al., 2019). As Losacker et al. (2023) note, "*the regional studies community lacks a critical overview of the importance of regions in the development and diffusion of environmental innovations*" (Losacker et al., 2023b, p. 293). Secondly, the role of the institutional context in shaping green innovation has received limited attention. Addressing this gap is particularly important from the perspective of Regional Innovation Systems (RIS) (Cooke et al., 1997), as well as evolutionary approach (Iammarino, 2005), which posits that innovation results from complex interactions among diverse actors within a specific institutional context (Marques and Morgan, 2021; Ortega and Serna, 2020; D'Agostino and Scarlato, 2019; Camagni and Capello, 2005; Edquist, 1997). Thirdly, from the seminal work of Rodríguez-Pose and Di Cataldo (2015) and Rodríguez-Pose (2013), scholars have increasingly recognized institutions' critical role in developing and adopting innovation. According to Crescenzi and Rodríguez-Pose (2009), formal and informal institutions are essential for fostering innovation, as they serve as a "social filter" influencing a region's capacity to convert innovation inputs into outputs. In other words, institutional quality is fundamental in determining both a region's innovative capacity and its technological advancement (Zhang and Rodríguez-Pose, 2024; D'Ingiullo and Evangelista, 2020; Rodríguez-Pose and Zhang, 2020; Tebaldi and Elmslie, 2013). Despite this recognized importance, the relationship between institutional quality and green innovation remains underexplored (Chen et al., 2024; Belso et al., 2024; Rodríguez-Pose and Zhang, 2020).

Building on these premises, this paper investigates the role of Institutional Quality (IQ) and green innovation in Italy. Specifically, it examines how varying levels of IQ influence regional capacity for generating green innovation, distinguishing between the impacts of economic and political institutions. A panel of data for 2004–2018 is analyzed using an IV approach and a Lewbel technique to control for endogeneity. The results show that the most important drivers of green innovation are related to the quality of political institutions. These findings remain robust, even when checking for economic and environmental controls, demonstrating that green innovation is more related to political decisions and social capital than innovation in general is.

The paper is structured as follows. Section 2 revises the literature on institutions and innovation, while Section 3 deals explicitly with green innovation. Section 4 provides data and methods used for the empirical analysis. Results are presented in Section 5 and discussed in Section 6.

2. Institutions and innovation

In 1990, North defined institutions as the entities establishing the "rules of the game" within a society (Rodríguez-Pose, 2013; North, 1990). These rules, in turn, shape collective social norms influencing individual behavior, affecting individuals' risk-taking, creativity, and problem-solving, all of which impact the innovation process (D'Ingiullo and Evangelista, 2020; Crescenzi and Rodríguez-Pose, 2009). Institutions, thus, play a vital role in supporting the innovative process and in fostering innovative growth within a region by creating conditions for investments, collaboration among diverse actors, and economic interactions (Rodríguez-Pose and Di Cataldo, 2015; Tebaldi and Elmslie, 2013; Rodríguez-Pose, 2013).

To date, institutions can influence regional innovation in various ways. First, weak institutions deter investment in innovation, while favorable legal frameworks—such as tax incentives for research and development or robust intellectual property protections—encourage companies to invest in new ideas and technologies (Clo' et al., 2020; Butenko and Larouche, 2015; Rodríguez-Pose and Storper, 2006). Thus, institutions are responsible for establishing the framework for learning processes and facilitating knowledge exchange between different and often competing actors (Zhang and Rodríguez-Pose, 2024; Yuang et al., 2022; Rodríguez-Pose and Di Cataldo, 2015). Second, highly bureaucratic institutions discourage economic agents from engaging in innovative activities due to high transaction costs, increased uncertainty, and an inability to create environments that support knowledge and technology transfer, along with the generation of new ideas (Rodríguez-Pose and Zhang, 2020; North, 1990). Third, weak institutions are often associated with corruption. While not directly linked to innovation, corruption reduces institutional trust, which hinders investment in innovative activities (Rodríguez-Pose et al., 2021). Transparent and uncorrupted institutions support the development of a fair regulatory structure and judicial system, lowering the economic and social costs associated with uncertainty (D'Ingiullo and Evangelista, 2020; Levchenko, 2007). Finally, poor institutional quality negatively affects policy formulation and implementation, crucial to supporting innovation (Alam et al., 2019). Policy uncertainties arising from weak and unstable institutions can deter long-term investment in innovation. Conversely, effective policies increase companies' propensity to engage in R&D activities (Rodríguez-Pose and Di Cataldo, 2015).

At the empirical level, research underscores the importance of institutional quality as a prerequisite for regional innovative performance (D'Agostino and Scarlato, 2015). One of the pioneering studies in this area is that of Rodríguez-Pose and Di Cataldo (2015), who examined the relationship between institutional quality and innovative performance in European regions using a production function approach. For institutional quality, they used the Quality of Government (QoG) index developed by Charron et al. (2014), which includes four dimensions: control of corruption, rule of law, government effectiveness, and government accountability. Their findings indicate that high-quality governance is a significant driver of innovation in European regions, with the QoG index showing a positive and significant relationship with innovative development. Specifically, Rodríguez-Pose and Di Cataldo (2015) found that high corruption levels and weak policymaking capacity are substantial barriers to innovation. Similar findings were observed by Tebaldi and Elmslie (2013) in the United States, where institutional quality was assessed through various measures, including "rule of law" (perceptions of trust in government), an aggregate measure of institutional quality based on variables from Kaufmann et al. (2010), and "risk of confiscation and forced nationalization." More recently, Rodríguez-Pose and Zhang (2020) conducted a study on China, confirming previous findings and showing that poor institutional quality at the local level impedes firms' innovative capacity. They identified weak rule of law, low regulatory quality, and high corruption levels as the primary institutional barriers to innovation.

In Italy, i.e., the territorial setting of this research, D'Ingiullo and Evangelista (2020) conducted a provincial analysis to assess the role of institutional quality in fostering innovation. By examining the aggregate Institutional Quality Index (IQI) from Nifo and Vecchione (2014) and its specific dimensions, they found that several interacting factors shape a province's innovative performance. Specifically, they observed that social capital—measured through indicators of cooperation and association—and voice and accountability, reflected by voter turnout and book publishing/purchasing rates, positively influence a province's innovative performance in Italy (D'Ingiullo and Evangelista, 2020).

3. Institutional quality, green innovations, and sustainable development

There is a growing global concern about sustainable development and green growth (Chen et al., 2024; Amin et al., 2023; Obobisa et al., 2022), and increasing attention has been given to understanding how to support economic development while controlling environmental impacts (Galliano et al., 2023; Losacker et al., 2023a; Sheng and Ding, 2023; Yuan et al., 2022). Existing research has demonstrated that green innovations play a critical role in fostering economic development while reducing energy consumption (Chen et al., 2024). Simultaneously, recent studies (e.g., Chen et al., 2024; Kılıçaslan et al., 2024; Amin et al., 2023) have highlighted the importance of institutional quality and its effects on promoting sustainable development.

Regarding green innovation and energy consumption, Ali et al. (2019) show, in their study of 47 developing countries, that institutional quality is positively associated with reductions in carbon dioxide emissions. More recently, Paramati et al. (2022), in a study of 28 OECD countries using panel data from 1990 to 2014, identified a positive correlation between green innovation and energy efficiency. Consistent results were also observed in South Asian countries; for instance, Amin et al. (2023) used advanced dynamic techniques and long-term estimation methods to demonstrate that green technology significantly reduces CO_2 emissions.

The role of institutional quality in sustainable development has garnered increasing attention from scholars, as environmental regulations and policies largely depend on national and regional institutions. Institutions also play an essential role in promoting renewable energy usage and reducing emissions through various policy instruments (Obobisa et al., 2022).

In terms of innovation, there is strong evidence that institutional quality can enhance green innovation, mainly through mechanisms such as those mentioned above. For example, Chen et al. (2024), Amin et al. (2023), and Dam et al. (2023) argue that robust institutions protecting intellectual property rights (IPRs) and enforcing environmental regulations encourage investment in green innovations. Khan et al. (2023) emphasize the importance of the rule of law, finding that stringent environmental policies promote green innovation, reducing carbon emissions. Additionally, research has shown that corruption negatively impacts green innovation, energy consumption, and sustainable development (Lu et al., 2022; Rahman and Sultana, 2022; Huang et al., 2021; Danish and Wang, 2019).

Despite the rising interest in institutional quality, much of the existing literature has focused on its effects on environmental sustainability rather than its direct relationship with green innovation. This gap is significant because, on the one hand, empirical research demonstrates that strong institutions positively influence innovation. On the other hand, there is growing concern over how to support economic growth and innovation while mitigating environmental impacts.

The present paper contributes to the extant literature in two main ways. First, it explores for the first time how differences in IQ affect Italian regional capacity to generate green innovation. This aspect connects the paper to the recent strand of research that adds some "soft" determinants to the classical ones in explaining regional innovation capacity. Second, it disentangles the effects related to economic institutions (i.e., corruption, government effectiveness, and regulatory quality) from the impacts associated with political institutions (i.e., rule of law and voice and accountability), controlling for regions' environmental and economic characteristics.

4. Data and method

4.1 Dependent variable

To measure regional green innovation in Italy, we use the number of green patent applications per million inhabitants in the period 2004–2018. Following Pinate *et al.* (2024b), three approaches to identifying green patents are employed. This is because using only a source to measure green-relate inventions can bias the results, and many scholars suggest their integration (Favot et al., 2023; Ghisetti and Quatraro, 2017). First, the International Patent Classification (IPC) Green Inventory by the World Intellectual Property Organization (WIPO) is included. This methodology contains seven macro areas: alternative energy production; transportation; energy conservation; waste management; agriculture and forestry; administrative, regulatory or design aspects; nuclear power generation. Second, the ENV-TECH by OECD is used, which is also divided into seven macro areas: environmental management; water-related adaptation technologies; biodiversity protection and ecosystem health; climate change mitigation related to energy generation, transmission of distribution; capture, storage, sequestration or disposal of greenhouse gases; climate change related to transportation; climate change related to buildings. Finally, the Y02/Y04S Tagging scheme by the European Patent Office (EPO) is added. This source includes only two categories: climate change mitigation technologies and smart grid.

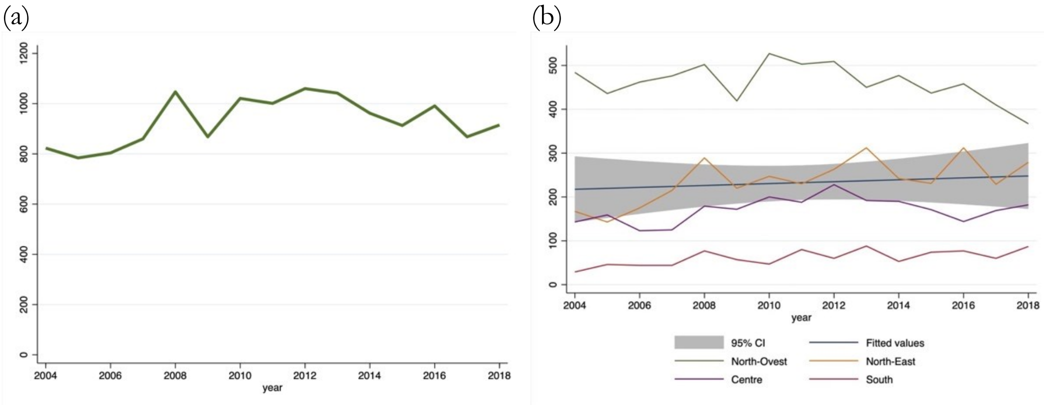
The three methodologies taxonomies described above are considered a good proxy of eco-innovation and have been used by several scholars to measure inventions in green-related technologies (Durán-Romero and Urraca-Ruiz, 2015; Cvijanović et al., 2021; Cohen et al., 2021; Bellucci et al., 2023). To get the broadest possible coverage and to ensure the findings are not influenced by the selected classification method, the three classifications were merged by creating a list of non-duplicated green codes. It is essential to notice that they overlapped only partially (in 24% of the cases).

Figure 1a shows the number of green patents in Italy – as a result of the merger described above – for the period 2004–2018. The trend is slightly positive (mean variation 0.23%), with a maximum peak in 2011. However, the variation is not linear and presents some negative rates (for instance, in 2009), signaling that there is an active interest in the development of the green economy.

The presence of green patents is not homogeneous along the country, but, as one can notice in Figure 1b, the Northwest is the macro-region with the highest number, while the South is the one with the lowest. The spatial distribution of the average over the period of analysis shows how green applications are more common in the North and some of the central regions (Figure 2). This divide is constant during the period analyzed and confirms what was already found by Pinate et al. (2024b) also for 2019.

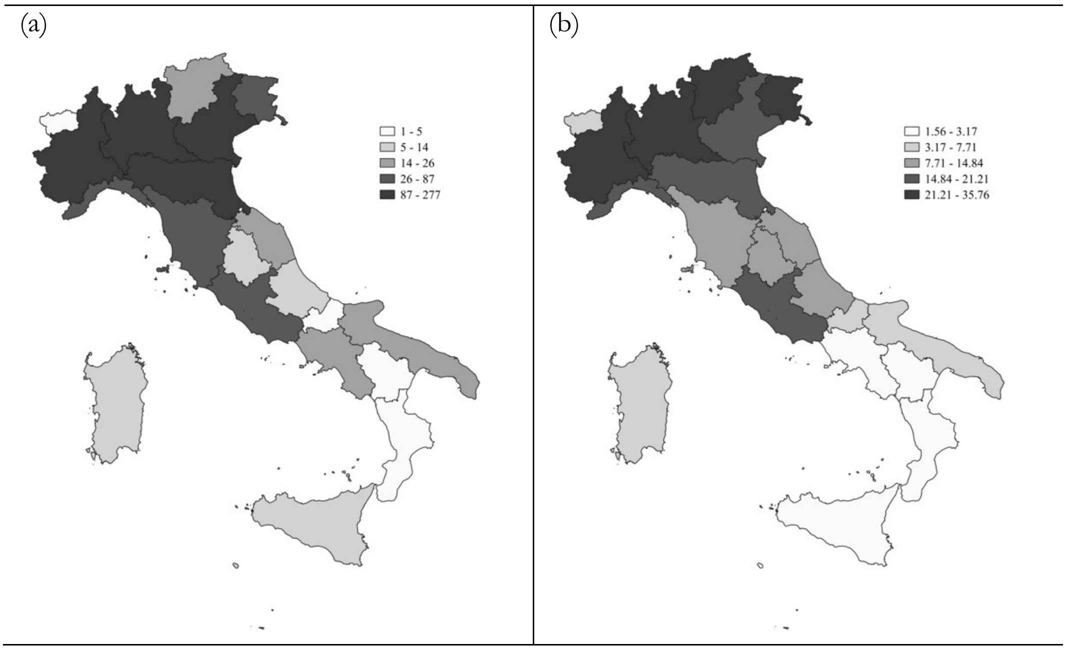
Figure 1. Number of green patents in Italy. Years 2004-2018

(a) (b)



Note: Authors' elaboration on OECD-REGPAT. Figure displays (a) green patent applications -total- and (b) per macro-regions over the period 2004-2018.

Figure 2. Green patent applications in Italy. Years 2004-2018



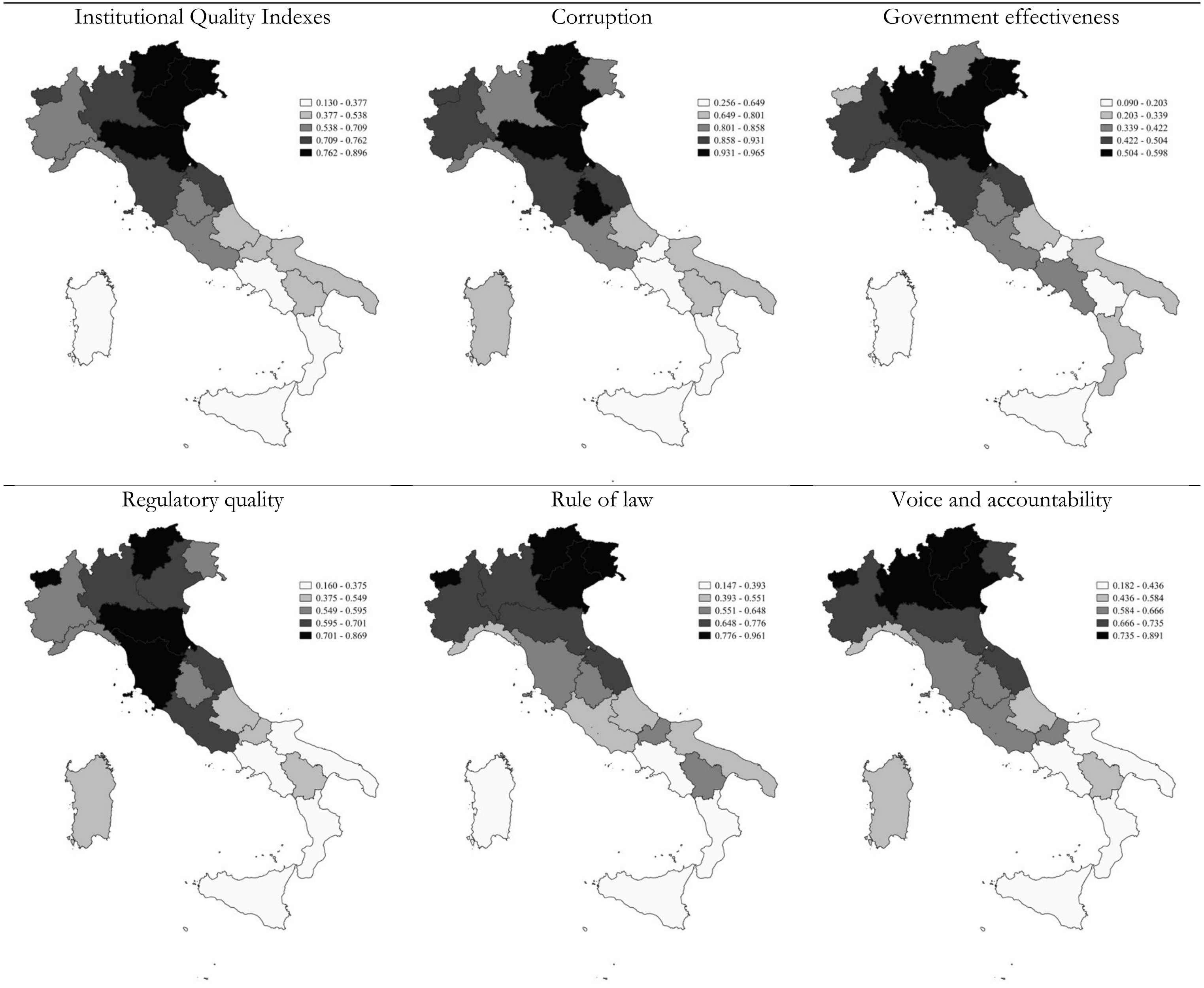
Note: Authors' elaboration on OECD-REGPAT. Figure (a) mean of green patent application and (b) mean of green patent applications per million of inhabitants over the period 2004-2018 -equal quantiles-.

4.2 Institutional quality

Data on institutional quality are from the dataset by Nifo and Vecchione (2014). These authors developed a composite indicator (IQI) by using and aggregating 24 different measures into five main indexes: *Corruption*, *Government effectiveness, Regulatory quality, Rule of law,* and *Voice and accountability*. We use this last aggregation in our analysis and the composite index IQI, which are all standardized and vary between 0 and 1 (1 being the higher institutional quality) and are available at the regional level (NUTS-2). It is essential to notice that, as D'Ingiullo and Evangelista (2020) explained, the first three sub-dimensions are more related to the economic aspect, while the last two are more related to the political one. Regarding the political aspect, we consider the *Rule of law* formal, while *Voice and accountability* as informal institutions. We expect that, as suggested by Belso et al. (2024), these two variables will have a strong impact on green innovation.

The internal disparities are also evident in the spatial distribution of IQI across the Italian regions (Figure 3). The maps endorse the persistent institutional dualism of the central-northern regions, which consistently exhibit a higher IQI than their southern counterparts.

Figure 3. Institutional Quality. Years 2004-2018



Note: Mean over the period 2004-2018 -equal quantiles-.

4.3 Methodology

To examine whether measures of the quality of institutions indexes and their five dimensions affect the green innovative performance of Italian regions, our econometric analysis relies on an extended knowledge production function (KPF) approach, i.e., adopts a place-based perspective with regions (NUTS-2) as a unit of observation. [1] This specification of the KPF is usual in the literature on regional innovation and used by previous works that have studied the effects of institutions and policies on innovation (Crescenzi et al., 2015; Rodriguez-Pose and Di Cataldo, 2015; D'Ingiullo and Evangelista, 2020). Our model equation follows the next form:

$$lnGP_{i,t} = \beta_0 + \beta_1 lnGP_{i,t-1} + \beta_2 IQ_{i,t}^{k} + \beta_n X_{n,i,t} + \eta_t + \mu_t + \varepsilon_{i,t} \qquad (1)$$

Where *i* are the regions (1, 2, …, 20), and *t* the time covered by the data (2004-2018). The dependent variable, $lnGP_{i,t}$, is measured by the natural logarithm of green innovation per million inhabitants[2]. To retain zeros, we followed a quite common procedure and added 0.001 before taking the logarithm (see Pinate et al., 2024a). The dependent is subtracted on both sides and lagged one year, as customary in dynamic panels (Rodriguez-Pose and Di Cataldo, 2015). IQ is our variable of interest, superscript *k* indicates the five dimensions of IQ; and $X_{n,i,t}$ is a vector of additional *n* time-variant controls (demographic, economic and environmental). The model also includes time effects (η_t), time-invariant macro-territorial North-South (μ_t)[3], and $\varepsilon_{i,t}$ is the idiosyncratic error term.

The set of control variables – demographic, economic, and environmental – are added to the model step by step to check if the significance of IQ measures is confirmed in boosting green innovation. On the one hand, demographic and economic controls included are quite standard in the literature and are traditional elements of a KPF, such as private R&D and the socio-economic structure of the region (Rodriguez Pose and Crescenzi, 2008; Rodriguez-Pose and Di Cataldo, 2015); but also environmental controls that are an element of originality (see variables description in Table 1).

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[1] We use regions (NUTS-2) as the functional economic unit for two main reasons. The first one is that as we work with green patents, many provinces have had zero green applications for several consecutive years (about 30% in the period 2004-2018). Secondly, the quality of institutions indicator of Nifo and Vecchione (2014) varies across regions rather than between provinces from the same region.

[2] As we see in Fig. 1a, the growth of green patents is not sustained. Thus, we decide to follow the work of D'Ingiullo and Evangelista, 2020 and use the natural logarithm.

[3] Due to the limited within-region temporal variation in green patenting activity (most variation is cross-sectional) and time-invariant institutional quality indicators, a macro-territorial South dummy is included to account for Italy's systemic North-South divide. As our research focuses on cross-regional institutional disparities (e.g., how persistent institutional characteristics drive green innovation), fixed effects would absorb the variation of interest. Di Liberto and Sideri (2015) show that Italy is affected by significant inter-regional differences can be considered by capturing the Northen-Centre and Southern heterogeneity (De Pascale et al., 2024). In our panel data, the IQ measures exhibit high inertia over time, especially in the southern regions with entrenched administrative traditions.

We add *Population density*, *Human capital,* and a dummy *South*[4] as demographic variables. We expect a positive sign for population and human capital, meaning that green patents are developing in highly populated urban areas by people with high levels of education (Ansaris et al., 2016; Lai, 2023). On the contrary, we expect a negative sign for the dummy South because of the well-known Italian North-South divide. Nonetheless, by controlling for this binary divide, we mitigate omitted variable bias related to time-invariant regional characteristics (e.g., historical dualism, cultural norms) that could confound the relationship between green patents and institutional quality.

We include *Private R&D, Manufacturing employment,* and *Large firms* as controls of the economic structure of regions. Different sectors exhibit distinct tendencies towards patenting; the manufacturing sector, in particular, patents a significantly greater proportion of its innovations compared to the services sector. Moreover, large companies are substantially more active in the patenting process. Empirical evidence further indicates a positive correlation between sectors exhibiting high patent output and those allocating substantial resources to research and development (R&D) investments (Bottazzi and Peri, 2003). Therefore, following the previous literature on innovation in general (Crescenzi et al., 2013; Rodriguez-Pose and Di Cataldo, 2015), the three variables are expected to impact green innovation positively.

Finally, as environmental controls, we use *Renewable Sources* (share of gross electricity production from renewable sources), *Environmental certification* (share of organizations with ISO 14001), and *Air pollution* (PM10). While green innovation shows promise in increasing the use of renewable sources and addressing pollution concerns, the complex relationship between environmental factors and green innovation is still in its infancy. Recent studies highlight how regional factors play a crucial role in the diffusion of green innovation, with geographical proximity to renewable energy plants being a significant driver (Horbach and Rammer, 2018). Regional green orientation can also be measured by voluntary *environmental management certification* of local firms and *pollution*. On the other hand, authors such as Hu et al. (2023), who also use the ISO 14001 certification, report that this accreditation enhances both the quantity and quality of green innovations in Chinese companies. At the same time, Brogi and Menichini (2019) found no significant correlation between ISO 14001 certification and eco-innovation performance indicators at the EU country level. Finally, we include a PM10 measure, a standard metric for assessing air pollution levels. This variable serves as a local indicator since its concentration remains largely unaffected by neighbouring regions, staying near the emission (De Pascale et al., 2024). Literature on the effect of local sources of pollution and green innovations shows heterogeneous results. Research indicates that higher levels of air pollution, measured by PM10, are associated with increased green innovation among entrepreneurs and firms (Guo et al., 2023; Ma and He, 2023). However, other studies as the one of Wang et al. (2021) found that exogenous pollution sources may decrease green innovation rates. Here, the hypothesis is that even if these variables affect green innovation, the significance of *IQI* will remain stable.

[4] Southern: Abruzzo, Basilicata, Calabria, Campania, Molise, Apulia, Sardinia, Sicily. Northern-Centre: Valle d'Aosta, Piedmont, Liguria, Lombardy, Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, Emilia-Romagna, Tuscany, Marche, Umbria, Lazio.

In Table 1 and Table 2, we provide a detailed description of variables, their source, and a summary statistic. Appendix A.1 illustrates the Pearson correlations for all variables and indicates no significant collinearity issues among the covariates. Instead, *IQ* measures are correlated with each other, so following D'Ingiullo and Evangelista (2020), they enter the model one at a time.

Table 1. Variables description

Variables	Definition	Sources
Green Patent [a]	Number of green patent applications per million of inhabitants	OECD-REGPAT
Institutional Quality measures		
IQI (synthetic indicator)	Composite indicator that summarizes the five distinct dimensions of IQ, which are derived from the aggregation of twenty-four indices	Nifo and Vecchione (2014)
Corruption	Index that includes 1) crimes against the public administration over the number of public servants; 2) the number of overruled municipalities on total municipalities; 3) the Golden–Picci Index [b]	Nifo and Vecchione (2014)
Government effectiveness	Index that includes 1) endowment of social and 2) economic facilities; 3) regional health deficit per capita; 4) separate waste collection; 5) urban environment index	Nifo and Vecchione (2014)
Regulatory quality	Index that includes 1) economy openness; 2) local government employees; 3) business density; 4) business start-ups/mortality; 5) business environment index	Nifo and Vecchione (2014)
Rule of law	Index that includes 1) crime against property; 2) crime reported; 3) trial times; 4) magistrate productivity; 5) submerged economy; 6) tax evasion	Nifo and Vecchione (2014)
Voice and accountability	Index that includes 1) social cooperatives; 2) associations; 3) elections participation; 4) books published; 5) purchased in bookshops	Nifo and Vecchione (2014)
Demographic controls		
Population Density [a]	Population per square kilometer	ISTAT. Development Policy Statistics
Human Capital	Number of individuals with tertiary education as a percentage of population	ISTAT. Development Policy Statistics
South	Dummy variable that values 1 if the region is located in the South; 0 otherwise	Own elaboration

Economic controls		
Private R&D	R&D expenditure from the business sector (enterprises and private nonprofit institutions) as a percentage of GDP	ISTAT. Development Policy Statistics.
Manufacturing employment	Share of employment in manufacturing as a percentage of total employment	ISTAT. Development Policy Statistics
Large firms	Share of employment in large scale enterprises (250 employees or more) as a percentage of employment	ISTAT. Statistical Register of Active Enterprises (ASIA)
Environmental controls		
Renewable Sources	Share of gross electricity production from renewable sources (including hydro) as a percentage of gross domestic electricity consumption measured in GWh	ISTAT. Development Policy Statistics
Environmental certification	Share of organizations with ISO 14001 (International Organization for Standardization)[c] environmental certification as a percentage of total of certified organizations	ISTAT. Development Policy Statistics.
Air pollution [d]	PM10 (emission of particulate matter in the atmosphere for vehicle transportation) -max. value-	ISPRA. Institute for Environmental Protection and Research

[a] The variables enter the model log-transformed.

[b] This index is computed as a difference between the amounts of physically existing public infrastructure and the amount of money cumulatively allocated by the government to create these public works.

[c] The ISO 14001 defines criteria for an environmental management system (EMS). It does not state requirements for environmental performance but maps out a framework that a company or organization can follow to set up an effective EMS.

[d] The variable enters the model divided by 1000. For a robustness check, we also control by using another air pollution measure, NO2 nitrogen dioxide, and the results remain invariant.

Table 2. Summary statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
Green Patent (log)	300	-6.895	0.011	-6.908	-6.858
IQI	300	0.572	0.239	0.055	0.982
Corruption	300	0.79	0.185	0.207	0.99
Government effectiveness	300	0.362	0.163	0.049	0.69
Regulatory quality	300	0.538	0.199	0.087	0.966
Rule of law	300	0.573	0.233	0.063	1
Voice and accountability	300	0.582	0.207	0.118	0.979
Population Density (log)	300	5.042	0.623	3.624	6.114
Human Capital	300	0.098	0.021	0.054	0.174
South	300	0.4	0.491	0	1
Private R&D	300	0.529	0.384	0.021	1.853
Manufacturing employment	300	0.526	0.109	0.198	0.745
Large firms	300	0.148	0.101	0.006	0.484
Renewable Sources	300	0.15	0.173	0.002	0.873
Environmental certification	300	0.115	0.047	0.020	0.323
Air pollution	294	0.105	0.037	0.036	0.359

Notes: All variables are at the NUTS-2 level and correspond to 2004-2018. The PM10 values (air pollution) are unavailable for 2004 and 2005 for Molise, Campania Calabria.

4.4. Instrumental Variable Approach

The presence of some potentially endogenous variables among the explanatories and the dependent variable of our model, presented in equation (1), and the unobservable heterogeneity contribute a source of potential reverse causality to be accounted for. As previous research hints, a stronger regional quality of institutions can modify the output of innovation, but, at the same time, we cannot exclude that regions with higher green patent activity may attract political or economic investments that subsequently improve institutional quality (e.g., funding for R&D, better governance). This nexus can comprehend different types of no-green and green patents (Barbieri et al., 2023). Additionally, endogeneity may also emerge from omitted variable bias even after including our controls (e.g., cultural attitudes toward sustainability, historical industrial specialization) that could influence IQ and green innovation. Our data do not allow us to have information on specific regional policies supporting green patenting. We can also not exclude a positive correlation with non/environmental policies, creating an overall bias in our coefficient of interest.

The empirical strategy employs a two-stage least squares Instrumental Variable (2SLS-IV) approach in institutional quality, using instruments as an exogenous source of variation. An IV approach isolates exogenous variation in the explanatory by leveraging instruments that satisfy their relevance, i.e., correlate with the institutional quality indexes, and the exclusion restriction, i.e., affects green patents only through its impact on institutional quality. We need to isolate the exogenous variation in different dimensions of IQ; thus, we rely on three variables used as instruments: historical educational attainment (graduates over resident population in the year 1951), public administration human resources (log of Public Administration R&D personnel -full-time-), and waste management efficiency (recycling rates). These variables function through enduring institutional legacies or state capacity, fulfilling exclusion restrictions. Moreover, the South dummy, incorporated in our regressions, accounts for wider regional disparities, isolating the instrument's impact on institutional channels.

The historical educational endowments proxy long-term regional capacity to develop effective institutions. The use of the 1951 year, the first census available by level of education source by ISTAT, pre-dates modern green innovation trends, reducing reverse causality concerns. While education is associated with innovation, the historical instrument reflects institutional legacies (such as civic culture and bureaucratic traditions) rather than current regional innovation capacity. Historical educational endowments have been used as an instrument for innovation outcomes, mitigating endogeneity associated with path dependence (Tabellini, 2010; Rodríguez-Pose and Di Cataldo, 2015).

Another instrument included is the public administration R&D personnel. Public R&D personnel concentrate on administrative and regulatory functions rather than direct development of green technology. Their influence on green patents is channeled by enhanced institutional quality (e.g., specific environmental regulations, implementing best practices in governance, and technology-driven public digitalization service) rather than private-sector R&D spillovers. Studies suggest that governments with a strong R&D workforce produce more effective policies, as technical expertise allows policymakers to comprehensively assess economic, social, and technological challenges (Rodríguez-Pose and Di Cataldo, 2015). Research by Guo et al. (2016) highlights how public personnel involved in government R&D foster a culture of accountability (rule of law), since often trained in rigorous methodologies that emphasize transparency and empirical validation. In a recent empirical investigation, Astakhov (2022) shows how public administration personnel's education and competence are crucial for sustainable development in Russia. Authors find that human resources in public administration, professional education of municipality personnel, have been the most important factors in the successful and sustainable socioeconomic development of regions in Russia.

A third instrument included is waste management efficiency. This variable measures the capability of the territory to reduce environmental pressures, used as a proxy for ecological transition (De Pascale et al., 2024), and also considered as an environmental policy enforcement (Mazzanti and Zoboli, 2009). The recycling capability of regional governments may rely on consumer diligence in waste segregation but also on the operational dynamics of institutions within a given territory, encompassing both legal and informal norms (Pronti and Zoboli, 2024). In Italy, the sorted waste collection is coordinated by regions that provide financial and technical support to provinces and municipalities, defining the separated collection guidelines and goals[5]. In Italy, extensive literature has addressed waste management and the role of local policies (Agovino et al., 2018; De Pascale et al., 2024; Cascioli et al., 2024), showing how regions with robust institutional frameworks are more likely to prioritize sustainable practices. Thus, while waste policies may incentivize recycling technologies, the percentage of separated waste reflects pre-existing institutional priorities with measures of environmental enforcement capacity (e.g., regulatory compliance, citizen trust in government) rather than outcomes of green innovations.

Working with one potentially endogenous variable per regression allows us to formally test their validity for each model corresponding to each *IQ* dimension. Valid instruments enable us to uncover the causal effect. The overidentifying restrictions test (Sargan-Hansen J statistics) indicates if our instruments are valid, i.e., the joint null hypothesis is uncorrelated with the error term and that the excluded instruments are correctly excluded from the estimated equation (Baum et al., 2015). In our estimations, the J-test (p-value >0.05) fails to reject overidentification (see Table 5). Furthermore, the F-stat of joint significance of the instruments in the first stage regression shows that our instruments are indeed not weak (i.e., F-statistic of at least 10, proposed by Staiger and Stock (1994)), and therefore relevant. Standard errors are robust to account for heteroskedasticity and adjusted for finite-sample bias (small option; Baum et al., 2015). Robustness to spatial heterogeneity is ensured via a South dummy and time-varying controls.

5. **Results**

In the first regression analysis, we estimate a simple model using only demographic controls and institutional quality measures (Table 3). In Model 1, the IQI is used, while in Models 2-6, the single components of this index are split and considered one by one. What is essential to notice is that the *IQI*, which includes many variables, is positive and highly significant. Still, it is difficult to interpret because of the heterogeneity of internal measures. For this reason, following De Pascale et al. (2024) and D'Ingiullo and Evangelista (2020), we consider more explanatory the single sub-dimensions: *Corruption, Government effectiveness, Regulatory quality, Rule of law, Voice and accountability*. Among these, four out of five show a coefficient that is positive and highly significant (1% significance level for three of them). *Corruption* is the only component of IQI that does not affect the dependent variable, *Green Patents* per capita. These results are in part in line with the results of D'Ingiullo and Evangelista (2020), who found a positive correlation between the total number of patents and government effectiveness, regulatory quality, and voice and accountability at the provincial level in Italy. This means that the determinants of green patents differ from those of patents in general and that some are more relevant in predicting green patents than total patents. For instance, the variable rule of law, considered a formal political institution, has a key role in green innovation while being found irrelevant for total patents. Among the control variables, *Population density* shows the expected sign and is statistically significant in most model specifications. The one-year lag of

[5] In 1997, Italian law began to be concerned with the proper waste management process through a Legislative Decree 22/1999, named Ronchi Decree. The main rules governing environmental regulations are "Testo Unico Ambientale" (Legislative Decree 152/2006), which contains the main rules governing environmental regulations. It establishes the regions' responsibilities in environmental matters, including separate collection.

the dependent variable is positive and statistically significant, meaning that the past number of green patents affects the actual one.

Table 3. IV regression results: demographic controls

VARIABLES	(1) GPcap	(2) GPcap	(3) GPcap	(4) GPcap	(5) GPcap	(6) GPcap
GPcap $_{t-1}$	0.478***	0.533***	0.502***	0.512***	0.491***	0.443***
	[0.092]	[0.083]	[0.089]	[0.091]	[0.091]	[0.097]
Pop Density	0.003***	0.002	-0.000	0.004***	0.004**	0.004***
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Human Capital	-0.019	-0.038	-0.027	-0.065*	-0.001	-0.061**
	[0.030]	[0.028]	[0.031]	[0.033]	[0.036]	[0.031]
South	-0.002	-0.007***	-0.003	-0.000	-0.003	-0.002
	[0.002]	[0.002]	[0.002]	[0.003]	[0.002]	[0.002]
IQI	0.015***					
	[0.005]					
Corruption		0.001				
		[0.007]				
Government effectiveness			0.023***			
			[0.008]			
Regulatory quality				0.024***		
				[0.008]		
Rule of law					0.012**	
					[0.005]	
Voice and accountability						0.022***
						[0.007]
Constant	-3.620***	-3.217***	-3.433***	-3.390***	-3.529***	-3.862***
	[0.637]	[0.578]	[0.612]	[0.635]	[0.631]	[0.675]
Observations	300	300	300	300	300	300
R-squared	0.682	0.680	0.650	0.635	0.683	0.685
First stage F-stat	55.84	19.31	18.83	22.22	22.25	25.39
Hansen *pvalue*	0.063	0.003	0.181	0.721	0.0147	0.137
Endogeneity *pvalue*	0.030	0.626	0.001	0.000	0.208	0.079
Underidentification *pvalue*	0.000	5.70e-09	5.26e-07	4.45e-09	1.32e-07	1.55e-08

Notes: The dependent variable is the natural logarithm of green patents. See Table 1 for variables descriptions. Estimates on Italian regions (NUTS2) over the period 2004–2018. Robust standard errors in brackets. Significance levels: *** p < 0.01, ** p < 0.05, * p < 0.10.

In the second regression analysis, we add some economic controls to the previous step (Table 4). The significance of *IQI* and sub-dimensions has not changed, with the magnitude of coefficients maintained. Moreover, by controlling for the presence of a strong private sector that invests in R&D, the number of employees in manufacturing, and the presence of large firms, we find that *Private R&D* and *Large firms* are highly and positively correlated with green patents. These outcomes confirm the relevance of the R&D expenditure and the agglomeration economies already found for patents in general (D'Ingiullo and Evangelista, 2020). The lagged dependent variable is positive and statistically significant, but the magnitude decreases due to the inclusion of other regressors.

Table 4. IV regression results: economic controls

VARIABLES	(1) GPcap	(2) GPcap	(3) GPcap	(4) GPcap	(5) GPcap	(6) GPcap
GPcap $_{t-1}$	0.220**	0.272***	0.248**	0.246**	0.232**	0.229**
	[0.099]	[0.096]	[0.098]	[0.100]	[0.103]	[0.101]
Pop Density	0.001	-0.001	-0.002**	0.002	0.002	0.002*
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Human Capital	-0.058	-0.061	-0.075	-0.100**	-0.038	-0.076
	[0.045]	[0.042]	[0.047]	[0.049]	[0.042]	[0.048]
South	0.001	-0.007***	-0.002	0.000	-0.001	-0.002
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.002]
Private R&D	0.010***	0.010***	0.010***	0.011***	0.010***	0.010***
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
Manufacturing empl	-0.005	0.013**	0.001	0.002	0.001	-0.002
	[0.008]	[0.006]	[0.007]	[0.007]	[0.008]	[0.008]
Large Firms	0.013**	0.016**	0.018***	0.015**	0.015**	0.006
	[0.006]	[0.006]	[0.007]	[0.006]	[0.006]	[0.006]
IQI	0.019***					
	[0.007]					
Corruption		-0.005				
		[0.008]				
Government effectiveness			0.022**			
			[0.010]			
Regulatory quality				0.021***		
				[0.008]		
Rule of law					0.013*	
					[0.008]	
Voice and accountability						0.019***
						[0.007]
Constant	-5.399***	-5.013***	-5.182***	-5.212***	-5.319***	-5.336***
	[0.683]	[0.658]	[0.670]	[0.689]	[0.715]	[0.697]
Observations	300	300	300	300	300	300
R-squared	0.732	0.735	0.708	0.708	0.736	0.737
First stage F-stat	25.19	14.28	14.79	18.42	14.99	18.01
Hansen *pvalue*	0.543	0.052	0.612	0.819	0.128	0.278
Endogeneity *pvalue*	0.004	0.476	0.001	0.001	0.056	0.050
Underidentification *pvalue*	1.72e-08	7.05e-06	2.12e-07	2.69e-06	7.01e-06	6.77e-06

Notes: See Table 3 for the description.

Finally, we add some environmental controls to the model (Table 5). This more complete model shows that three out of five variables related to *IQI* are statistically significant. First, the coefficient of *IQI* lost in magnitude and significance with respect to the previous model estimated. Among the sub-dimensions, *Regulatory quality*, *Rule of law*, and *Voice and accountability* affect green patents. However, it is crucial to notice that only the political aspects maintain the statistical significance at 1%. This result reflects that the quality of political institutions is more relevant for green innovation with respect to the quality of economic institutions and extends to previous findings by Belso et al. (2024) and Xue et al. (2024), who showed that informal institutions play a crucial role in green technology innovation. Our estimations also corroborate our first intuition regarding the fact that not every sub-indicator of *IQI* is relevant for green innovation, but there exists a difference between economic and political institutions.

The mechanism under which green innovation develops is guided by the presence of traditional variables, such as, for instance, the expenditure on R&D, but also by strong law enforcement and solid social capital. Indeed, a region with a more efficient legal system and a lower propensity for the occurrence of crime or tax evasion tends to increase the number of green patents. At the same time, the higher the participation in public elections, the phenomenon of associations, the number of social cooperatives, and cultural liveliness – in terms of books published and purchased in bookshops – the higher the incidence of green patents. Interestingly, in all our regressions, corruption is the only *IQ* that does not affect green innovation, and it also appears to have a negative coefficient. Several studies suggest that controlling corruption decreases innovation output (Bariş, 2019; Heo et al., 2019), especially in developed economies where bureaucratic procedures are more severe and might depress innovation activities in the long term.

By controlling for some environmental-related variables, we find that the correlation with environmental certifications is negative, in line with Brogi and Menichini (2019), which also does not find a significant correlation between ISO 14001 certification and eco-innovation performance indicators at the EU country level. Conversely, regions with higher levels of pollution (PM10) or with a higher share of use of renewal sources do not appear significant. Previous research on the correlation between these environmental variables and green innovations is heterogeneous.

A series of tests shows the robustness of our results. In all our estimations, the J-test (p-value >0.05) fails to reject overidentification (see Table 5)[6], indicating that our instruments are valid. The F-stat of joint significance of the instruments in the first stage regression shows that our instruments are indeed not weak (F>10).

Table 5. IV regression results: environmental controls

VARIABLES	(1) GPcap	(2) GPcap	(3) GPcap	(4) GPcap	(5) GPcap	(6) GPcap
GPcap $_{t-1}$	0.196**	0.238**	0.230**	0.212**	0.175*	0.184*
	[0.094]	[0.094]	[0.094]	[0.094]	[0.099]	[0.096]
Pop Density	-0.000	-0.003**	-0.003**	-0.000	0.001	0.001
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]

[6] In some regressions, the endogeneity tests fail to reject the null hypothesis, i.e., OLS is consistent, even though the instruments are both exogenous and relevant (columns 5-6, Table 5). As Demko (2012) notes, weak correlations between the instrument and the error term may not always be ruled out, even when instruments are strong. To address this issue, we re-estimate the equations using a Limited Information Maximum Likelihood (LIML) estimator (Pinate et al., 2023). The LIML method is considered more robust than the instrumental variable (IV) estimator in cases where instruments are numerous (Bascle, 2008; Murray, 2017). The results obtained from the LIML estimation validate those produced from the two-stage least squares (2SLS) method.

Human Capital	-0.074*	-0.072*	-0.083**	-0.109**	-0.048	-0.087**
	[0.040]	[0.041]	[0.042]	[0.044]	[0.042]	[0.042]
South	-0.002	-0.009***	-0.004	-0.003	-0.001	-0.003
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
Private R&D	0.012***	0.012***	0.011***	0.012***	0.012***	0.012***
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
Manufacturing empl	-0.004	0.012**	0.001	0.001	-0.005	-0.005
	[0.007]	[0.006]	[0.007]	[0.006]	[0.007]	[0.007]
Large Firms	0.010*	0.013**	0.015**	0.012*	0.011*	0.002
	[0.006]	[0.006]	[0.007]	[0.006]	[0.006]	[0.006]
Renewable Sources	-0.001	-0.003	0.000	-0.001	-0.001	-0.004
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
Environmental certif	-0.042**	-0.043**	-0.027	-0.046**	-0.056***	-0.051***
	[0.017]	[0.017]	[0.020]	[0.018]	[0.017]	[0.018]
Air pollution	-0.006	-0.009	-0.002	-0.011	-0.009	-0.006
	[0.008]	[0.008]	[0.009]	[0.009]	[0.008]	[0.008]
IQI	0.014**					
	[0.006]					
Corruption		-0.009				
		[0.007]				
Government effectiveness			0.016			
			[0.010]			
Regulatory quality				0.013*		
				[0.007]		
Rule of law					0.017**	
					[0.007]	
Voice and accountability						0.018***
						[0.006]
Constant	-5.540***	-5.228***	-5.297***	-5.427***	-5.690***	-5.626***
	[0.646]	[0.644]	[0.643]	[0.646]	[0.680]	[0.658]
Observations	294	294	294	294	294	294
R-squared	0.743	0.732	0.719	0.734	0.742	0.748
First stage F-stat	33.92	18.47	14.79	22.19	14.05	22.78
Hansen *pvalue*	0.222	0.051	0.199	0.168	0.181	0.379
Endogeneity *pvalue*	0.017	0.044	0.0021	0.007	0.055	0.067
Underidentification *pvalue*	2.49e-10	9.78e-07	1.17e-06	3.88e-09	4.07e-06	8.70e-07

Notes: See Table 3 for the description.

6. Conclusions and Policy Implications

The role of institutional quality in determining green innovation has received limited attention. This is even truer if the regional context is analyzed (Losacker et al., 2023b). As

Crescenzi and Rodríguez-Pose (2009) pointed out, formal and informal institutions are essential for fostering innovation, as they serve as "social filters" influencing their capacity to convert inputs into outputs. While this aspect has been recently analyzed for the specific case of Italy by D'Ingiullo and Evangelista (2020), which followed the seminal paper by Rodríguez-Pose and Di Cataldo (2015) on European regions, a gap concerning the relationship with green innovation is identified.

The growing attention to the twin transition, digital and green, which characterizes the recent European Agenda, is an objective for economic and sustainable growth in the long run. For this reason, and with the aim to fill a gap in the literature, this paper focused on how Italian regions foster green innovation and, in particular, on the role of different types of institutional quality. Using the sub-dimensions provided by Nifo and Vecchione (2014), we developed a model able to disentangle the single effects of economic and political institutional quality. The estimates concern 20 Italian regions (NUTS2) for the timespan 2004-2018, and we checked for endogeneity issues by using an IV approach.

The main findings can be summarized into three points. First, the relevance of political institutions, rather than economic, in fostering green innovation. Second, the difference between different sub-indicators of IQI matters. Third, the determinants of innovation and green innovation are not the same, with informal institutions playing a crucial role in the latter.

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Appendix A.1 Pairwise correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) *GPcap*	1.000															
(2) *IQI*	0.664	1.000														
(3) *Corruption*	0.495	0.772	1.000													
(4) *Government effect*	0.604	0.709	0.394	1.000												
(5) *Regulatory quality*	0.529	0.875	0.707	0.495	1.000											
(6) *Rule of law*	0.526	0.911	0.709	0.412	0.829	1.000										
(7) *Voice and account*	0.607	0.917	0.727	0.516	0.836	0.868	1.000									
(8) *Pop Density*	0.256	-0.085	-0.164	0.437	-0.173	-0.341	-0.204	1.000								
(9) *Human Capital*	0.302	0.323	0.198	0.476	0.294	0.114	0.355	0.237	1.000							
(10) *South*	-0.698	-0.854	-0.703	-0.694	-0.798	-0.717	-0.751	-0.142	-0.393	1.000						
(11) *Private R&D*	0.758	0.520	0.303	0.608	0.376	0.367	0.458	0.363	0.414	-0.574	1.000					
(12) *Manuf empl*	0.272	0.284	0.220	0.357	0.150	0.171	0.293	0.130	0.208	-0.129	0.254	1.000				
(13) *Large Firms*	0.591	0.423	0.365	0.544	0.362	0.187	0.419	0.523	0.518	-0.588	0.587	0.108	1.000			
(14) *Renewable Sources*	-0.331	-0.357	-0.419	-0.263	-0.379	-0.319	-0.232	-0.187	0.176	0.477	-0.188	0.078	-0.355	1.000		
(15) *Environ certif*	-0.032	0.168	0.033	-0.024	0.168	0.268	0.250	-0.416	0.328	-0.037	0.110	0.208	-0.233	0.271	1.000	
(16) *Air pollution*	0.131	-0.029	-0.056	0.084	-0.042	-0.070	-0.099	0.377	-0.238	-0.045	0.148	0.029	0.179	-0.203	-0.362	1.000

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