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Strengthening Institutions for a Green and Digital Future: Regional Evidence from Europe's Twin Transition

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ABSTRACT

This paper explores the role of institutional quality in fostering the twin transition across European regions. We construct a novel panel dataset at the NUTS2 level (2006–2020), combining patent data from the OECD REGPAT with the European Quality of Government Index. Twin transition innovation is measured through the fractional count of patents in technologies simultaneously addressing environmental sustainability and digital transformation. Institutional quality is captured both through EQI and its key dimensions. Using a Tobit regression model with panel data, we find that higher institutional quality significantly increases the likelihood and intensity of twin transition patenting

1 | Introduction

Over the past decade, there has been significant interest across Europe in promoting the green transition as a means of fostering economic growth while minimizing environmental impact (Guarascio et al. 2026). This focus has intensified in the aftermath of the COVID-19 pandemic, as European governments have turned their attention not only to the green transition but also to the digital one, a dual and complementary process widely known as "twin transition" (Barbero et al. 2025; Marrocu et al. 2025; Brueck et al. 2025; Faggian et al. 2025; Fazio et al. 2025). The importance of the twin transition in Europe is evident in initiatives such as the Next Generation EU (NGEU) program, European Green Deal and in the substantial resources allocated within National Recovery Plans to support this transformation (Barbero et al. 2025; Marrocu et al. 2025; Bănică et al. 2024; De Pascale et al. 2024; Rodríguez-Pose and Bartalucci 2024).

In this context, the regional level has been receiving increasing attention, leading Faggian et al. (2024) to call for further research into what they term the *regional geography of twin transition* (Faggian et al. 2025, p. 2). At the regional level, a vast body of literature demonstrates in fact that the spread and location of innovation are not evenly distributed across regions (Collini and Hausemer 2024; Rodríguez-Pose and Bartalucci 2024; Bianchini et al. 2023; Boschma and Martin 2010), highlighting that different regional factors have to be considered when examining innovation development and adoption (Damioli et al. 2025; Rodríguez-Pose and Villarreal Peralta 2015; Crescenzi and Rodríguez-Pose 2011). This perspective is well supported by extensive research on regional innovation systems (RIS) (Asheim et al. 2011; Cooke 2008; Cooke et al. 1997), evolutionary economic geography (Boschma and Frenken 2018, 2006; Kogler 2015; Boschma and Martin 2007) and geography of sustainability transition (Barbero et al. 2025). These fields emphasize that innovation emerges from the systemic interactions of various regional factors and the complex networks of different actors (Barbero et al. 2025; Barbieri et al. 2020; Ortega and Serna 2020; Horbach et al. 2014; Edquist 1997).

Among the various actors influencing innovation, institutions, and the quality of government more in general, have proven to be a key factor in either facilitating or hindering both general innovation (Zhang and Rodríguez-Pose 2024; D'Ingiullo and Evangelista 2020; Rodríguez-Pose 2020; Boudreaux 2017; Tebaldi and Elmslie 2013; Crescenzi and Rodríguez-Pose 2009) and the green one (Pinate et al. 2025; De Pascale et al. 2024;

Sun et al. 2019). Research generally distinguishes between formal and informal institutions, with the former referring to transparent and codified rules (Rodríguez-Pose 2020) shaping human and social interactions (Rodríguez-Pose and Storper 2006; Boschma 2005; North 1990) and thus able to different dimensions related to economic development (Lasagni et al. 2015; Acemoglu and Johnson 2005). Informal institutions, on the other hand, are mainly related to values such as trust, social capital, and tolerance (Rodríguez-Pose 2020). Taking a regional perspective, research (see, e.g., Charron et al. 2014) have shown how institutional quality varies across territories at the subnational level, becoming a fundamental variable in explaining not only the (different) innovative trajectory of territories, but also the socio-economic development (Cutrini 2023; Bottasso et al. 2022; Rodríguez-Pose 2020). Lastly, the role and the quality of institutions become even more critical in transitional phases, where *economy and society move from a dominant setting to another* (De Pascale et al. 2024, p. 691). This transition involves a multifaceted set of socio-economic actions, regulations, and public policies, making it *more than just a policy change* (Collini and Hausemer 2024, p. 868).

Despite the acknowledged importance of regional contexts, relatively few studies have adopted a regional perspective (Damioli et al. 2025; Marrocu et al. 2025), and even fewer have specifically examined the role of institutional quality in the twin transition (Bănică et al. 2024; Brueck et al. 2025; De Pascale et al. 2024; Bianchini et al. 2023). Such a perspective is becoming more and more relevant in the light of the potential for green and twin transition to increase territorial discontent, further leading to a regional polarization and jeopardization of the geography of discontent. As recently highlighted by Rodríguez-Pose and Bartalucci (2024), in fact, this transition potentially may have indirect negative effects, especially in terms of labor markets dynamic, human capital migration and smart specialization strategy, that should be mitigated for a stronger role of institutions. In other words, institutions are key players in the match among twin transition, discontent and economic development.

Starting from these premises, and especially from the recognition that (i) the adoption and development of innovation is deeply rooted in regional and local characteristics of territories, (ii) institutions and the quality of government is one fundamental variable in the equation explaining economic and innovation development, and that (iii) it varies across regions, this study investigates the role of institutional quality in advancing the twin transition across European regions. Specifically, this research investigates the role of institutional quality in advancing the twin transition across European regions. In doing so, it aims to contribute to the ongoing call for a deeper exploration of the regional and territorial dimension of the twin transition and its key determinants, with a particular focus on the effect of institutional quality. Furthermore, this study also widely recognizes the interconnections between twin transition, development trap, institutions and the potential for polarizing discontent across European regions.

To achieve this research objective, we use data from multiple key sources, including OECD REGPAT and EUROSTAT, i.e., patents registered with the European Patent Office (EPO) related to sustainable technologies as defined by the EPO's Y02/Y04S tagging scheme. For digital patent we used: Internet of Things (IoT), Cloud Computing, Big Data, Robotics, 3D Printing and Artificial Intelligence (AI). Institutional quality is measured using the European Quality of Government Index (EQI), developed by the Quality of Government Institute (Charron et al. 2019), both at the aggregate level and considering its single dimensions (i.e., impartiality, administrative efficiency and corruption control). Methodologically, we estimate a Tobit panel model, appropriate given the censored nature of patent fractional count data and the high presence of zeros across regions and years. This approach allows us to model both the probability of patenting activity and its intensity, conditional on occurrence (Bianchini et al. 2023; Wooldridge 2019).

Our main findings show that institutional quality, intended as an aggregate index, supports twin transition and, at the same time, its three dimensions separately considered have a significant and positive impact on twin transition across European regions.

This study offers three main contributions. First, it provides novel empirical evidence on the role of regional institutional quality as a key enabler of twin transition, a topic still underexplored in the literature. Second, it advances the geography of twin transition literature by combining patent data on green and digital technologies into a unified measure of twin transition, allowing for spatially disaggregated analysis. Third, by employing a robust econometric approach and high-quality regional data, it generates actionable insights for EU cohesion policy and regional innovation strategies.

The paper proceeds as follows. Section 2 provides an overview of the spatial anatomy of twin transition across Europe; Section 3 summarizes the theoretical framework, reading twin transition first through the lens of development trap and geography of discontent and, then specifically focusing on the role of institutions. Data, variables and methods are presented respectively in Section 4. Results are presented in Section 5, and Section 6 concludes and highlights policy implications and limitations of the study.

2 | Spatial Anatomy of the Twin Transition in Europe

Regional and evolutionary economists have widely demonstrated that innovation does not diffuse uniformly across territories (Collini and Hausemer 2024; Rodríguez-Pose and Bartalucci 2024; Bianchini et al. 2023; Boschma and Frenken 2018). Instead, the spread, adoption, diffusion and impact of innovation is shaped by distinct region-specific conditions (Rodríguez-Pose and Villarreal Peralta 2015; Crescenzi and Rodríguez-Pose 2011) as well as from cognitive and spatial embeddedness (Damioli et al. 2025; Storper 2018; Capello 2002). In this, twin transition innovation is not different, as also demonstrated by the growing literature on the topic.

Examining the impact of twin technologies on GHG emissions in EU metropolitan regions, Bianchini et al. (2023) show how digital technologies in particular, display highly uneven development across the EU, with Eastern and peripheral regions lagging behind. Their analysis also indicates that the diffusion of twin technologies is shaped by regional endowments. Specifically, the positive effect on GHG reduction is strongest in regions with substantial digital technological capacity, while the negative environmental effects associated with digital technologies are less pronounced in regions with a strong base of green technologies (Bianchini et al. 2023).

The different diffusion of green transition, as well the associated risk, is clearly shown by the work of Rodríguez-Pose and Bartalucci (2024). These authors, after identifying the direct and indirect impact of green transition, propose the Regional Green Transition Vulnerability Index, aimed at assessing the effect of such transition on regions and taking into account six different dimensions (i.e., fossil fuel dependency and emission; tourism; energy; transportation; agriculture and land use; industry). They mainly find that (i) metropolitan areas are less vulnerable to changes related to green transition while (ii) many lagging regions are much more vulnerable to the negative impact of green transition (Rodríguez-Pose and Bartalucci 2024).

Fazio et al. (2025) investigate the effect of innovative orientation and specialisation of regions (distinguishing between information and communication technology—ICT—and green technology) on twin transition across 259 European regions from a time horizon 1977–2018 and, overall, they found that *innovative orientation is, in general, spatially unequal* (Fazio et al. 2025, p. 16), with some regions being highly innovative, while others lagging-behind. Second, they highlight that the spatial distribution of ICT, green and twin technologies varies over time moving from high concentration in regions located in Central and Northern Europe to a more dispersed distribution in later years. Third, innovative orientation and specialization matters for twin transition: ICT-oriented regions are more likely to become twin oriented compared to green-oriented regions. Lastly, they confirm the relevance of spatial association and clustering, also when highly innovative regions are removed from the sample (Fazio et al. 2025).

Recognizing the relevance knowledge-base plays in twin transition, Damioli et al. (2025) analyze the spatial distribution of digital, green and twin scientific knowledge across NUTS-2 regions using three variables, i.e., quantity, quality, and visibility of scientific publications. Overall, they found that the topic diffuses over an increasing number of EU regions with a mostly defined spatial pattern that differs from that of patenting activities. In fact, these authors highlight twin scientific publications developed in specific regions of Italy, Finland, Portugal and Spain, while they register a weaker twin scientific production in Eastern Europe (Damioli et al. 2025).

Barbero et al. (2025) analyze twin transition at the regional level taking a slightly different perspective. The authors, by using a novel dataset and combining qualitative and quantitative approach, analyze the geographical distribution and the regional concentration patterns of European Regional Development Fund (ERDF) related to green, digital and twin projects. Overall, they found that ERDF projects follow a geographical pattern, with the highest concentration in the most polluting regions (Eastern and Western countries and some regions of Ireland, Finland and France). Furthermore, they also found that higher skilled human capital and good governance are associated with a greater propensity of ERDF funds allocation. Lastly, by adopting a qualitative approach, these authors show the existence of heterogeneity in twin transition regional policies, highlighting the relevance of place and space, as suggested by evolutionary economists (Barbero et al. 2025).

Marrocu et al. (2025) focus on how European regions address green, digital and twin priorities in their Smart Specialization Strategy (S3) during 2014–2020. These authors, by analyzing 1145 policies on 164 territorial units at NUTS-2 level, found territorial heterogeneity in the implementation of green and digital policies and, secondly, the impact of these policies on the regional performance depends on the initial development level of these regions.

These studies confirm that the spread and diffusion of twin transition depends on specific regional-context, in line with the main evolutionary economy and RIS framework. This, combined with the relevance of the topic from both an academic and policy perspective, needs further investigation, especially to develop place based policies and to mitigate the potential effect on (geography of) discontent and development trap in which institutions play a central role, as discussed in the next section.

3 | Theoretical Background

3.1 | Regional Development Trap, Discontent and Institutions

Although twin transition has been widely recognized as a driver for economic development, scholars also recently highlight the potential of twin transition to foster the process of regional development trap (Diemer et al. 2022) and territorial inequalities (Pike et al. 2016), especially for peripheral or non core regions (Roessler 2024). In other words, twin transition might also create winners and losers at the regional level.

The idea of development trap originated from the widely evidence that there is a *Europe at different speed* (Diemer et al. 2022, p. 488), with regions at both the top and the bottom of economic development being characterized by an economic and productive dynamism, while the middle-income regions being characterized by long-term stagnation and development "immobility." These trapped regions are characterized by low economic growth, limited productivity growth and unemployment (Diemer et al. 2022). Specifically, Diemer et al. (2022) define a regional development trap as a situation in which a region registers weak income, productivity and employment growth with respect to (i) its past economic performance, (ii) their country, and (iii) other similar European regions.

It is also recognized that being trapped for a long time can cause economic marginalization and social and political resentment, thus increasing the overall discontent in a territory (Roessler 2024; Greve et al. 2023; Diemer et al. 2022; Dijkstra et al. 2020). Specifically, discontent is defined as the *unhappiness experienced by people living in a mix of stagnating and low productivity regions—mainly rural areas and medium and small cities—as a direct consequence of the limited opportunities and economic prospect they face* (Dijkstra et al. 2020, p. 744). In fact, being trapped has fundamental consequences for the prosperity of residents and also on its perception about current economic performance with the previous ones and with similar territories (Rodríguez-Pose and Bartalucci 2024; Diemer et al. 2022).

Discontent, therefore, is a geographical phenomenon (Florida 2021), as demonstrated by the increasing literature of the geography of discontent (see, e.g., Lenzi and Perucca 2021; Dijkstra et al. 2020; McCann 2020; Rodríguez-Pose 2018), which highlights how political resentment strongly results from increased economic and social marginalization, economic stagnation low productivity and rising inequality (Rodríguez-Pose

and Bartalucci 2024; Bourdin and Torre 2023; Florida 2021; Lenzi and Perucca 2021; De Ruyter et al. 2021). In this context, institutions do play a central role (Karahasan and Pinar 2024; Bottasso et al. 2022; Ferrante and Pontarollo 2022; Agerberg 2017). Weak institutional quality, in fact, may increase dissatisfaction among inhabitants, thus generating political and social tensions (Torre and Bourdin 2026), while corruption has been found to be one of the sources of populism in Europe (Apergis and Pinar 2023). Interesting results are provided by the recent study of Karahasan and Pinar (2024), who, studying the effect of institutional quality on discontent and opposition in European regions, find that weak institutional quality is associated with votes for anti-Europe parties and that regions experiencing economic growth are less prone to vote for EU opposition.

There is, therefore, a complex interplay between regional development, institutions and discontent (De Ruyter et al. 2021). In this context, twin transition, with its potential to foster economic growth cannot be treated as a separate phenomenon, but, instead, it should be conceptualized and read in the light of these phenomena, especially from a policy perspective. In Marrocu et al. words' *if not properly addressed, this uneven exposure may fuel territorial discontent and political backlash, potentially undermining support for green transition itself* (Marrocu et al. 2025, p. 5). The challenges posed by the twin transition, in fact, with its secondary impact on productivity, innovation, skills and labor market, therefore need strong institutions in order to support an equal development of European regions, thus reducing inequalities among territories.

3.2 | Institutions, Innovation, and Twin Transition

There is broad consensus that regional disparities exist in both the diffusion and intensity of innovation, raising questions about the role of institutions in either fostering or hindering innovation (Zhang and Rodríguez-Pose 2024; D'Ingiullo and Evangelista 2020), and the context of twin transition is not an exception (see, e.g., Bănică et al. 2024; Rodríguez-Pose and Bartalucci 2024).

At a broader level, formal institutions shape economic growth and innovation by establishing the "rules of the game" within society (Cutrini 2023; Lasagni et al. 2015; Rodríguez-Pose 2013; North 1990). These rules, in turn, influence social norms that affect individual behavior, risk-taking, creativity, and problem-solving, crucial aspect for innovation to take place (D'Ingiullo and Evangelista 2020; Crescenzi and Rodríguez-Pose 2009; Acemoglu and Johnson 2005). Thus, institutions play a crucial role in enabling innovation and regional economic growth by fostering conditions for investment, collaboration among diverse stakeholders, and productive economic interactions (Lasagni et al. 2015; Rodríguez-Pose and Di Cataldo 2015; Tebaldi and Elmslie 2013; Rodríguez-Pose 2013).

The influence of institutions becomes even more significant during transitional periods, such as that of the twin transition. Strong and effective governance structures, well-established rule and regulatory frameworks, in fact, directly and indirectly affect the transition process, especially by influencing the behavior of economic agents and their decisions regarding business operations and investments (De Pascale et al. 2024; Geels et al. 2021). The extant economic and regional literature has identified several mechanisms through which institutional quality affects innovation.

Strong institutions foster investment in innovation, supporting tax incentives for R&D or strong intellectual property protections, thus encouraging companies to pursue new ideas and technologies (Butenko and Larouche 2015; Rodríguez-Pose and Storper 2006). Institutions also facilitate learning processes and knowledge exchange among diverse, often competing, actors (Zhang and Rodríguez-Pose 2024; Rodríguez-Pose and Di Cataldo 2015). Furthermore, strong institutions are often associated with low levels of corruption, which, although not directly tied to innovation, increases institutional trust and encourages investment in innovative activities. Transparent, uncorrupted institutions foster a fair regulatory environment, reducing the economic and social costs associated with uncertainty (D'Ingiullo and Evangelista 2020; Levchenko 2007).

Second, highly bureaucratic institutions can discourage innovation by increasing transaction costs, uncertainty, and barriers to knowledge and technology transfer (Rodríguez-Pose and Zhang 2020; North 1990). Conversely, government effectiveness, enforceable contracts, and protection of property rights improve the implementation of regulations at both national and regional levels (Culas 2007).

Moving to empirical research, extant studies show that institutional quality is particularly critical for green innovation, supporting smart specialization, facilitating the diffusion of sustainable technologies, and raising public awareness of environmentally friendly practices (Bănică et al. 2024; Appiah et al. 2022). While research on the intersection between institutional quality and the twin transition is still emerging (Bănică et al. 2024; De Pascale et al. 2024), its importance in driving green innovation is increasingly recognized.

Among the two dimensions of the twin transition, extant literature mostly focuses on environmental innovation. National and regional institutions play key roles in enforcing environmental regulations, promoting renewable energy, and reducing emissions through policy tools (Obobisa et al. 2022. Empirical studies support these findings: Chen et al. (2024) and Dam et al. (2023) show that strong institutions, especially those protecting intellectual property rights and enforcing environmental standards, promote investment in green innovation. On the other hand, corruption negatively impacts green innovation, energy consumption, and sustainable development (Rahman and Sultana 2022). A recent Italian study by Pinate et al. (2025) confirms that institutional quality, measured by the Institutional Quality Index (IQI) (Nifo and Vecchione 2014), positively influences green innovation. Among the five IQI components[1], "regulatory quality" and "voice and accountability" had the strongest impact.

Regarding the twin transition, two studies are especially noteworthy. Bănică et al. (2024), focusing on (i) investigating the role of different socio-economic factors (one of which is the institutional quality) and EU, and especially on those countries receiving substantial funds from the Recovery and Resilience Fund and (ii) understand whether less developed regions have the capacity to jointly implement both digital and environmental policy objectives, found that institutional quality

significantly affects the green and digital transition in European regions. Strong institutions are better equipped to implement long-term sustainable strategies and policies, while responsible and accountable institutions provide a solid foundation for transition efforts. In Italy, De Pascale et al. (2024) used the IQI to show that institutional quality plays a key role in supporting the green aspect of the twin transition, but not the digital one. They attribute their findings to the regulatory demands of sustainable innovation, whereas digital transformation may be more closely driven by economic factors, such as GDP, than by institutional conditions.

4 | Data and Sources

We constructed a database at the NUTS2 level by integrating information from several primary sources.

First, we used the OECD REGPAT database, from which patents registered with the European Patent Office (EPO) were extracted, focusing specifically on those related to eco-innovation and digital technologies. These patents were subsequently combined to identify those relevant to the so-called twin transition.

Second, institutional quality was measured using data provided by the Quality of Government Institute, which develops the EQI, based on citizens' perceptions of fairness, quality of public services and direct experiences of corruption in the public sector.

Third, additional socio-economic and technological control variables, such as Gross Domestic Product (GDP) and the number of people employed in knowledge-intensive sectors (used as a proxy for high-skilled human capital), were collected from the EUROSTAT database. Finally, we integrated data on regional innovation performance from the European Commission's Regional Innovation Scoreboard. A detailed summary of variables and related sources is presented in Table 1.

4.1 | Dependent Variables

To construct the *Twin transition* patent variable, which measures the number of patents related simultaneously to eco-innovation and digital technologies, we followed a two-step methodology. First, we identified eco-innovation patents and digital patents separately; subsequently, we selected those patents that overlapped between these two categories based on their patent codes.

For eco-innovation patents, we employed the OECD REGPAT database, utilizing the EPO's Y02/Y04S tagging scheme, which extends standard patent classifications by adding "Y" sections specifically dedicated to Climate Change Mitigation Technologies (CCMTs). This method is widely used to distinguish eco-friendly patents and is supported by studies from the Joint Research Centre (JRC) of the European Commission (Pasimeni et al. 2021).

For digital patents, we employed the approach used by Martinelli et al. (2021) to identify patents through CPC (Cooperative Patent Classification) codes. Specifically, this approach identifies the following Industry 4.0 enabling technologies: Internet of Things (IoT), Cloud Computing, Big Data, Robotics, 3D Printing and Artificial Intelligence (AI).

By integrating these two patent sets (eco-innovation and digital patents), we constructed the Twin Transition patent database measured at the NUTS2 level. Specifically, to construct our dependent variable, we follow Maraut et al. (2008) and we use fractional patent counts based on the applicant's address, a method that allows to allocate a share of each patent to the applicants' home NUTS2 regions, when co-applicants are involved (Leggerini et al. 2025).

4.2 | Independent Variables

To measure institutional quality, we use the EQI (Charron et al. 2019), both at the aggregate level (EQI) and considering

TABLE 1 | Variables used in the study.

Variable	Definition	Source
Dependent variables		
Twin transition	Number of patents made in Twin transition technologies	Orbis Intellectual Properties
Independent variables		
EQI	European quality of government index	Quality of Governament Institutes
Impartiality	Part of the EQI index that evaluates the level of impartiality	Quality of Governament Institutes
Administrative efficiency	Part of the EQI index that evaluates the level of administrative efficiency	Quality of Governament Institutes
Corruption control	Part of the EQI index that evaluates the level of control of corruption	Quality of Governament Institutes
Controls variables		
GDP	Gross domestic product in billions of €	Eurostat
HTECH	Employment in technology and knowledge-intensive sectors (thousand persons)	Eurostat
Innovation index	The regional innovation scoreboard (RIS) is a regional extension of the European innovation scoreboard (EIS), assessing the innovation performance of European regions	European Commission

Source: Author's elaboration.

separately each specific dimension. The *EQI* consists of individual-level data from a citizen-based survey conducted in 2010, 2013, 2017, and 2021, focusing on individual perceptions of three subdimensions (namely "impartiality," "administrative efficiency," and "corruption control") in education, public healthcare, and law enforcement within their communities. Thus, the EQI aims to evaluate the "quality" rather than the "quantity" of public services delivered by regional governments (Charron et al. 2019; Sundström and Wängnerud 2018). Since EQI data are available only for discrete survey waves, while patent outcomes are observed on an annual basis, we construct an interpolating. This approach is commonly adopted when dealing with slowly evolving institutional indicators and is justified by the high persistence of institutional quality over time. Interpolation allows us to approximate annual variation while preserving temporal continuity and avoiding artificial breaks in the institutional series (Flip and Setzer 2025).

Impartiality constitutes a component of the EQI index, which evaluates the capacity of public institutions to treat all individuals equitably, devoid of favoritism influenced by personal relationships, status, or other variables. Impartiality is assessed either by the sense of preferential treatment for certain individuals or by the conviction that all individuals receive equal treatment within public institutions, including education, healthcare, and law enforcement.

The EQI index also includes *administrative efficiency* as a component that evaluates the perceived effectiveness of public services, including health, education, and law enforcement. Citizens assess the efficacy of public services based on satisfaction and dependability. High administrative efficiency signifies the effective functioning and prompt responsiveness of public services to the requirements of citizens.

Corruption control, a component of the EQI index, reflects the population's perception and experience of corruption within public services. Corruption is characterized as the exploitation of official authority for personal benefit. Corruption encompasses citizens' encounters with bribery and their perceptions of favoritism and transparency inside governmental organizations.

4.3 | Control Variables

In addition to these independent variables, the study includes three control variables to account for other factors that might influence innovation output. First, we use the Gross Domestic Product (*GDP*) of the region at the NUTS2 level, expressed in millions of euros, which represents the economic size and research and development investment capacity of the region (Kinyar and Bothongo 2024). A second control variable refers to the number of employed in the high-tech sector (*HTECH*) (1000 persons) (Tal et al. 2024) and it used as a proxy for high-skilled human capital, which is recognized as a relevant factor for innovation (Pinate et al. 2024; Losacker et al. 2023). The *Innovation Index* is measured through the Regional Innovation Scoreboard, a composite indicator developed by the European Commission that captures regional innovation capacity across multiple dimensions, including R&D inputs, patenting activity, human capital, and knowledge-intensive employment (Nasir and Zhang 2024). To account for common macroeconomic shocks, policy cycles, and unobserved temporal dynamics affecting all regions simultaneously, we include a full set of year dummy variables in all model specifications. This time fixed effects control for EU-wide events and trends (such as the global financial crisis, the sovereign debt crisis, the gradual implementation of the European Green Deal, and the COVID-19 shock) without imposing any parametric assumption on the time profile of innovation. By absorbing common temporal variation, year dummies allow the estimated coefficients to capture the effect of regional institutional quality net of general time trends and shared external shocks.

4.4 | Method

The final panel dataset consists of 3536 observations across 221 NUTS2 regions from 2006 to 2020. This balanced structure provides sufficient variability both across time and regions to identify the effects of interest with reasonable precision.

The models were estimated using a Tobit panel regression, which is appropriate due to the censored nature of the dependent variable (Wooldridge 2019). Since patent counts often include many zeros (i.e., regions with no Twin Transition patents in certain years), the Tobit model accounts for this left-censoring at zero, ensuring consistent and unbiased parameter estimates (Bianchini et al. 2023). This approach allows us to model both the probability of a region having any patent activity in the Twin Transition domain and, conditional on having at least one, the intensity of that activity (Bianchini et al. 2023).

From an empirical perspective, our analysis followed a two-step approach. First, we examined the overall impact of institutional quality, using the composite EQI (EQI) as the main explanatory variable (model 1). Subsequently, we assessed the influence of each individual subcomponent of institutional quality by estimating separate models with the following models (model 2, 3, and 4). In these models, the dependent variable measures the number of Twin Transition patents at the regional (NUTS2) level, observed 2 years ahead to account for potential lags in innovation outcomes. We also include time fixed effects (YEAR) to control for unobserved temporal shocks that may influence all regions simultaneously.

We thus have:

Model 1: $\text{Twin transition}_{t+2} = \beta_0 + \beta_1\ \text{EQI}_{i,t} + \beta_2\ \text{GDP}_{i,t} + \beta_3\ \text{HTECH}_{i,t} + \beta_4\ \text{Innovation Index}_{i,t} + \beta_5\ \text{YEAR}_t + \varepsilon_{i,t+2}$ (1)

Model 2: $\text{Twin transition}_{t+2} = \beta_0 + \beta_1\ \text{Impartiality}_{i,t} + \beta_2\ \text{GDP}_{i,t} + \beta_3\ \text{HTECH}_{i,t} + \beta_4\ \text{Innovation Index}_{i,t} + \beta_5\ \text{YEAR}_t + \varepsilon_{i,t+2}$ (2)

Model 3: $\text{Twin transition}_{t+2} = \beta_0 + \beta_1\ \text{Administrative Efficiency}_{i,t} + \beta_2\ \text{GDP}_{i,t} + \beta_3\ \text{HTECH}_{i,t} + \beta_4\ \text{Innovation Index}_{i,t} + \beta_5\ \text{YEAR}_t + \varepsilon_{i,t+2}$ (3)

Model 4: $\text{Twin transition}_{t+2} = \beta_0 + \beta_1\ \text{Corruption control}_{i,t} + \beta_2\ \text{GDP}_{i,t} + \beta_3\ \text{HTECH}_{i,t} + \beta_4\ \text{Innovation Index}_{i,t} + \beta_5\ \text{YEAR}_t + \varepsilon_{i,t+2}$ (4)

5 | Results

Figure 1 shows the total number of patents in twin transition in the European Union, by application year, showing, overall, an increasing trend, except for 2021 and 2022, probably due to truncation bias (e.g., patent applications not yet granted) (Leggerini et al. 2025).

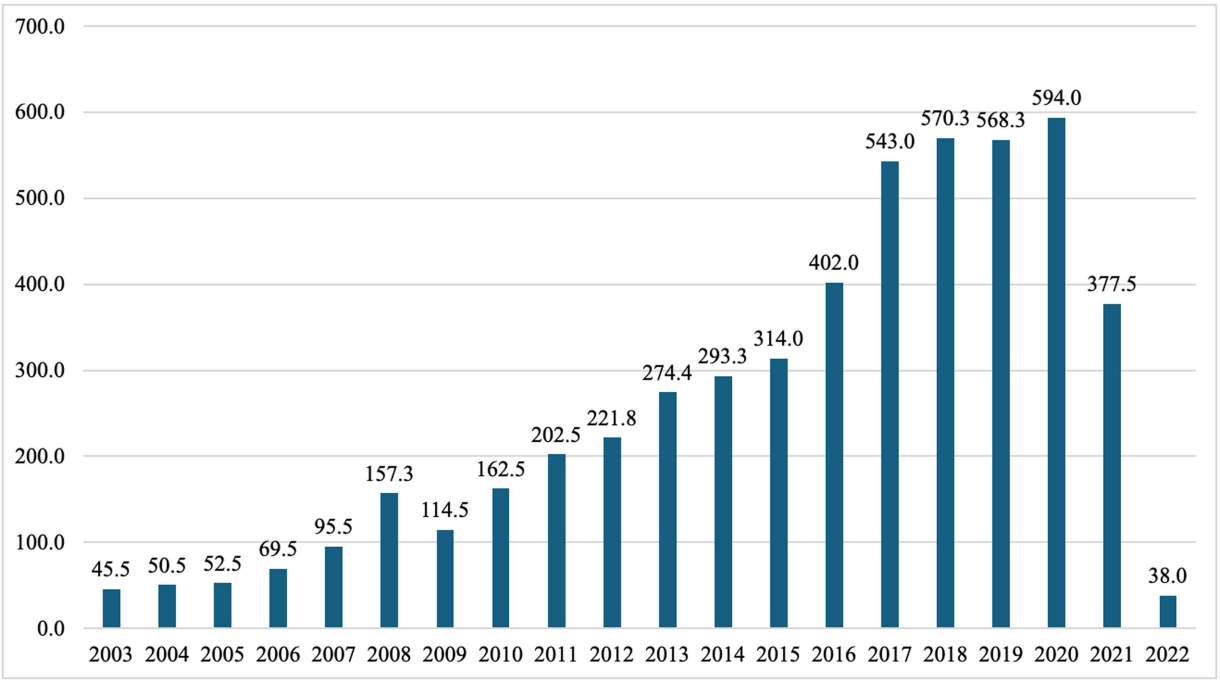

FIGURE 1 | Number of patents in twin transition over time. Source: author's elaboration. [Color figure can be viewed at wileyonlinelibrary.com]

The spatial distribution of Twin Transition patents across European NUTS2 regions reveals a jeopardized distribution across EU regions, with activity concentrated in a limited number of core areas (Figure 2). For visualization purposes, patent counts are reported in discrete intensity classes (0; 1–20; 20–40; 40–100; 100–200; 200–500; >500; NA), which makes cross-regional contrasts easier to interpret. In particular, southern Germany stands out as the leading hub, with the highest number of patents, exceeding 1200, suggesting a strong industrial and technological base capable of integrating green and digital innovations. Other active regions include parts of France and Northern Italy, though with significantly lower patent counts. Conversely, a vast portion of Europe (including large parts of Eastern and Southern countries) shows very limited or no patenting activity in the Twin Transition domain. This pattern indicates a strong East-West divide in innovation capabilities and reflects broader structural disparities in terms of research infrastructure, industrial specialization, and institutional support for innovation.

At the more general level, this findings is in line the extant literature of RIS as well as evolutionary economic geography, according to which the spread of innovation diffusion and adoption depend of regional characteristics and it is, basically, a geographical phenomenon (see, e.g., Collini and Hausemer 2024; Boschma and Frenken 2018; Rodríguez-Pose and Villarreal Peralta 2015; Crescenzi and Rodríguez-Pose 2011). This uneven distribution is also confirmed when twin transition is concerned. This is not a surprising result, given the heterogeneity of twin transition spatial anatomy, described in Section 2. This heterogeneous twin transition patent distribution maybe be explained by different reasons: innovative orientation and specialization (Fazio et al. 2025), spatial distribution of "twin scientific knowledge" (Damioli et al. 2025), concentration of development funds (Barbero et al. 2025) and Smart Specialization Strategy adoption (Marrocu et al. 2025).

Table 2 shows the descriptive statistics. Multicollinearity has been estimated through the Variance Inflation Factors (VIF). Table 3 shows the descriptive statistics for the selected variables, reporting a mean VIF value of 5.99 (Shrestha 2022). Table 3 provides the correlation matrix.

5.1 | Empirical Results

Empirical results are reported in Table 4.

In Model 1, *EQI* is positive and highly significant, indicating that regions with higher overall institutional quality are more likely to generate Twin Transition patents 2 years later ($b = 3.560$, $p < 0.001$) (Figure 3). This finding supports the idea that better governance conditions, such as effective public services, low corruption, and fair treatment of citizens, can foster environments conducive to green and digital innovation. In fact, in line with the current literature on innovation, high institutional quality and strong institutions favor innovation, through different channels. First, overall, by influencing social norms and individual behavior, high institutional quality is likely to favor risk-taking, creativity and innovative problem-solving approaches, ingredients that, in turn, are crucial for innovation development (Leggerini et al. 2025; D'Ingiullo and Evangelista 2020; Crescenzi and Rodríguez-Pose 2009; Acemoglu and Johnson 2005). In this sense, therefore, high quality of institutions influence the decision-making of economic agents regarding their business operations as well as investment to engage in the innovation path (Rodríguez-Pose and Storper 2006). Lastly, a high quality of institution could also support investment in innovation activities, especially through tax incentives, intellectual property protection and public R&D support (Leggerini et al. 2025).

In Model 2, *Administrative Efficiency* is positive and highly significant, suggesting that the quality and effectiveness of

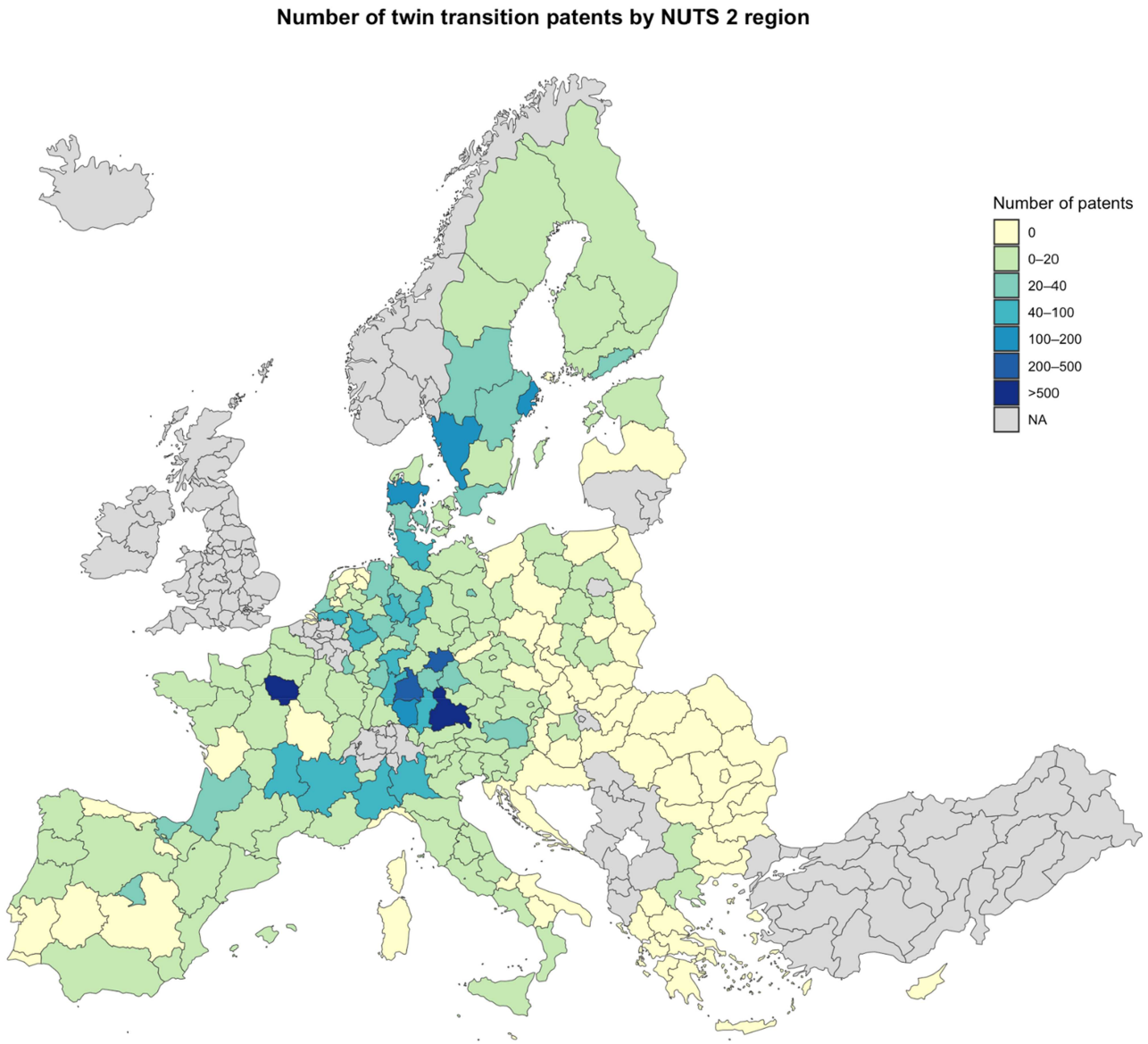

FIGURE 2 | Number of patents in twin transition NUTS 2. Source: author's elaboration. [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 2 | Descriptive statistics.

Variable	Obs	Mean	Std. dev.	Min	Max
Twin transition t-2	3536	1.311	7.204	0	166.333
Twin transition t-1	3536	1.157	6.636	0	166.333
EQI	3536	0.112	0.997	−3.004	2.822
Administrative efficiency	3536	0.103	0.998	−3.488	3.314
Impartiality	3536	0.108	0.998	−3.219	2.644
Control of corruption	3536	0.117	1.006	−2.913	2.572
GDP	3536	50714.159	64448.868	992.53	729515.61
HTEC	3536	30.75	42.203	0	423.9
Innovation index	3536	90.027	31.315	15.114	159.483

Source: Author's elaboration.

public administration directly contribute to higher levels of Twin Transition patenting ($b = 3.017$, $p < 0.001$) (Figure 4). In this respect, in fact, dealing with efficient public organization and administration can lower translation cost, favoring a fruitful and timely collaboration between public and private actors and, lastly, strengthening technology and knowledge transfer among institutions, thus maximizing the potential, for a region, to innovate (Rodríguez-Pose and Zhang 2020).

TABLE 3 | Correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Twin transition t-2	1								
(2) Twin transition t-1	0.916	1							
(3) EQI	0.148	0.143	1						
(4) Administrative efficiency	0.153	0.15	0.964	1					
(5) Impartiality	0.121	0.116	0.97	0.904	1				
(6) Control of corruption	0.153	0.147	0.967	0.894	0.911	1			
(7) GDP	0.393	0.375	0.183	0.169	0.159	0.201	1		
(8) HTEC	0.375	0.356	0.109	0.092	0.089	0.132	0.891	1	
(9) Innovation index	0.235	0.226	0.786	0.774	0.763	0.743	0.42	0.339	1

Source: Author's elaboration.

TABLE 4 | Econometric results.

	Model 1 Twin transition t-2	Model 2 Twin transition t-2	Model 3 Twin transition t-2	Model 4 Twin transition t-2
EQI	3.560***			
	(0.841)			
Administrative efficiency		3.017***		
		(0.764)		
Impartiality			3.201***	
			(0.781)	
Control of corruption				2.059***
				(0.700)
GDP	0.000128***	0.000125***	0.000129***	0.000125***
	(1.42e−05)	(1.41e−05)	(1.43e−05)	(1.41e−05)
HTEC	−0.0520**	−0.0513**	−0.0534***	−0.0560***
	(0.0205)	(0.0205)	(0.0206)	(0.0203)
Innovation index	0.118***	0.136***	0.129***	0.156***
	(0.0295)	(0.0277)	(0.0284)	(0.0271)
2006	0.131	0.144	0.148	0.176
	(1.575)	(1.576)	(1.577)	(1.586)
2007	1.519	1.555	1.552	1.589
	(1.510)	(1.510)	(1.512)	(1.521)
2008	3.568**	3.608**	3.602**	3.700**
	(1.447)	(1.447)	(1.449)	(1.456)
2009	1.328	1.343	1.409	1.442
	(1.497)	(1.499)	(1.497)	(1.507)
2010	3.304**	3.294**	3.389**	3.459**
	(1.442)	(1.445)	(1.443)	(1.452)
2011	3.681**	3.659**	3.799***	3.830***
	(1.450)	(1.452)	(1.450)	(1.459)
2012	4.581***	4.656***	4.720***	4.757***
	(1.423)	(1.422)	(1.422)	(1.432)
2013	4.904***	4.919***	5.038***	5.137***
	(1.424)	(1.426)	(1.423)	(1.431)
2014	6.251***	6.251***	6.390***	6.496***
	(1.395)	(1.397)	(1.394)	(1.402)
2015	5.717***	5.638***	5.820***	5.952***
	(1.404)	(1.408)	(1.404)	(1.411)
2016	7.693***	7.690***	7.849***	7.967***

(Continues)

TABLE 4 | (Continued)

	Model 1 Twin transition t-2	Model 2 Twin transition t-2	Model 3 Twin transition t-2	Model 4 Twin transition t-2
	(1.380)	(1.382)	(1.379)	(1.385)
2017	8.501***	8.493***	8.660***	8.763***
	(1.375)	(1.377)	(1.374)	(1.381)
2018	9.292***	9.294***	9.458***	9.567***
	(1.366)	(1.368)	(1.365)	(1.372)
2019	8.947***	8.894***	9.171***	9.313***
	(1.373)	(1.378)	(1.370)	(1.376)
2020	8.527***	8.538***	8.714***	8.844***
	(1.383)	(1.385)	(1.381)	(1.387)
Constant	−32.815***	−34.164***	−33.926***	−35.881***
	(2.994)	(2.897)	(2.911)	(2.845)
Sigma u	6.835***	6.749***	6.980***	6.669***
	(0.412)	(0.405)	(0.425)	(0.396)
Sigma e	7.705***	7.727***	7.695***	7.740***
	(0.156)	(0.156)	(0.156)	(0.156)
	(2.995)	(2.897)	(2.912)	(2.845)
Wald test	596.68***	601.83***	590.30***	598.14***
Observations	3536	3536	3536	3536
NUTS 2	221	221	221	221

Note: Standard errors in parentheses.
Source: Author's elaboration.
*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

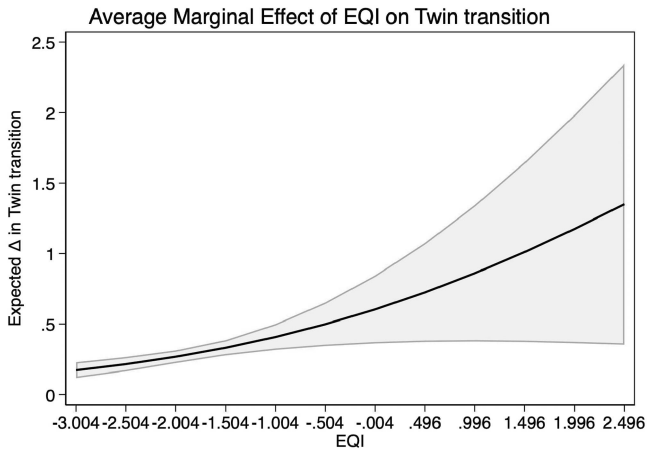

FIGURE 3 | Average marginal effect of EQI on twin transition. Source: author's elaboration.

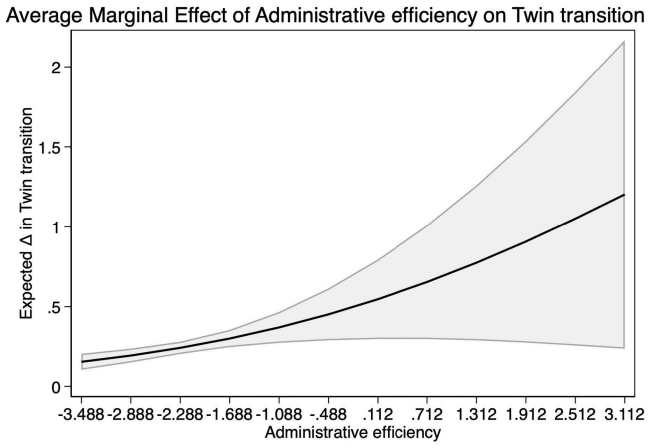

FIGURE 4 | Average marginal effect of administrative efficiency on twin transition. Source: author's elaboration.

Furthermore, effective and efficient institutions can foster (twin) innovation through the existence of enforceable contracts and strong protection of property rights (Culas 2007). Furthermore, effective institutions are better positioned to design and implement mission-oriented policies that explicitly align environmental and digital objectives, for instance through coordinated public procurement, targeted R&D subsidies, and recovery funding that incentivises complementarities between green and digital technologies rather than siloed innovation paths (Santos et al. 2023).

In Model 3, *Impartiality* shows a positive and statistically significant effect on Twin Transition patenting ($b = 3.201$, $p < 0.001$) (Figure 5). This indicates that in regions where public institutions act fairly and do not discriminate among citizens or firms, innovation outcomes tend to be more favorable. The result suggests that equitable governance can enhance trust and cooperation between public authorities and private actors, which is particularly important for the success of transitions requiring systemic coordination. By lowering coordination failures, facilitating cross-sectoral collaboration, and supporting open knowledge exchange, high-quality and impartial institutions governance enhance the capacity of regions to recombine green and digital knowledge bases into novel hybrid inventions (Bianchini et al. 2023). In addition, fair and impartial institutions help ensure equitable

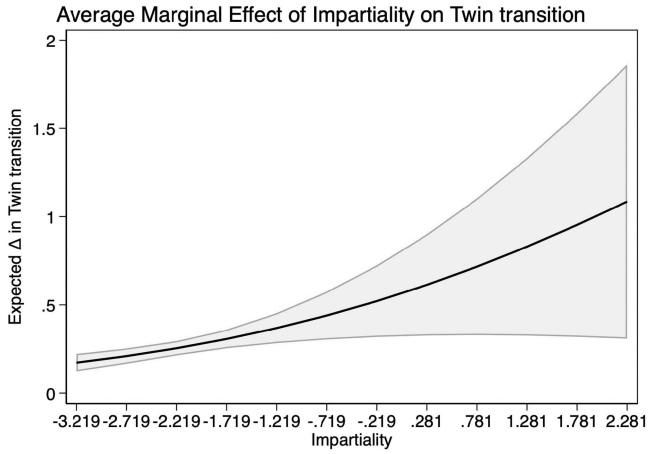

FIGURE 5 | Average marginal effect of impartiality on twin transition. Source: author's elaboration.

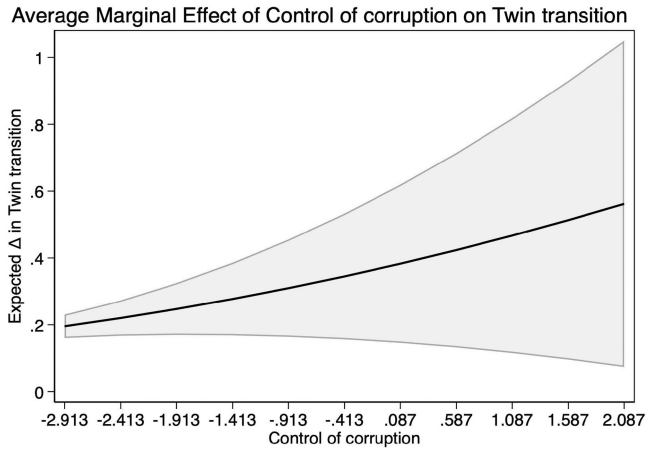

FIGURE 6 | Average marginal effect of control of corruption on twin transition. Source: author's elaboration.

access to support systems, grants, and innovation networks, thereby strengthening collaboration, trust, and collective learning among diverse stakeholders (Zhang and Rodríguez-Pose 2024; Rodríguez-Pose and Di Cataldo 2015). Such neutrality further fosters institutional legitimacy, standardized service delivery, and procedural stability, which together create a predictable and secure environment conducive to sustained digital advancement and long-term innovation trajectories (Nafeza et al. 2025).

In Model 4, *Control of Corruption* is also positive and highly significant ($b = 2.059$, $p < 0.001$), showing that lower levels of corruption are associated with higher levels of Twin Transition patenting (Figure 6). This finding underscores that transparent and accountable institutions play a vital role in supporting innovative activity. Reduced corruption likely improves the allocation of public resources, increases investor confidence, and ensures a level playing field, all of which are critical for enabling technological transitions. Extant studies show that a low level of corruption is expected to have a positive, although indirect, effect of investment in innovative activities, especially by increasing institutional trust from economic agents. Second, uncorrupted institutions may also define a fair and transparent regulatory environment reducing, in this way, the cost associated with uncertainty (D'Ingiullo and Evangelista 2020).

5.2 | Robustness Checks

Two robustness checks are performed. In the first (Table 5), we use a different time lag of 1 year, and in the second (Table 6), we use the inventors' addresses with 1- and 2-year lags. The results are consistent with the previous findings, as shown in Tables 5 and 6.

6 | Conclusion, Limitations, and Recommendations

Twin Transition is currently a highly debated topic in different disciplines and policy domains, especially due to its relevance in the NGEU program (Barbero et al. 2025; Marrocu et al. 2025) as well as the huge amounts of resources devoted within the National Recovery Plans after the Covid-19 pandemic (Bănică et al. 2024; De Pascale et al. 2024).

Among the different academic disciplines investigating the twin transition, that of regional studies is particularly promising, especially due to the widely recognized uneven distribution of technological innovation in general across European regions (Collini and Hausemer 2024; Rodríguez-Pose and Bartalucci 2024; Bianchini et al. 2023; Boschma and Martin 2010).

Moreover, and especially at the regional level, the uneven distribution of, first, green and, second, twin innovation may have the detrimental effect of widening the gap between regions, especially between the core regions and most developed, and those regions lagging behind. This is a relevant policy issue to be addressed for a set of different reasons.

First of all, as shown by Rodríguez-Pose and Bartalucci (2024) and Regional Green Transition Vulnerability Index they propose, green transition can lead also to negative and somewhat unexpected negative consequences, which will mainly affect regions lagging behind in development. This undoubtedly requires policy measures that can mitigate the gap between European regions, rather than exacerbate it.

Second, if it is widely recognized the potential for twin transition to support innovative and economic development, scholars must also be aware of the potential to be a (negative) cause for "trapping" regions. In fact, as the spatial anatomy of twin transition we present, it is clear that there is an uneven spatial distribution of twin transition-oriented innovation which not only can exacerbate territorial disparities, but can also lock in some regions.

Thirdly, and as a consequence of the different spatial distribution of twin transition innovation and the risk of "being trapped," there is a matter of discontent which should be addressed carefully. There is a wide consensus that the status of being trapped for a long time is a cause of discontent (see, e.g., Rodríguez-Pose and Bartalucci 2024; Roessler 2024; Dijkstra et al. 2020).

In this context, institutions play, and will play, a central role.

In fact, if, on the one hand, research on the geography of twin transition (Faggian et al. 2025) is achieving increasing relevance among regional scholars, the same can be said also for the role of institutions, and especially their quality, in fostering this transition (Collini and Hausemer 2024; De Pascale et al. 2024) and, thus, in preventing and mitigating the potential negative effect of twin transition, ensuring an even development of EU regions and preventing the acceleration of discontent.

TABLE 5 | Robustness test—1 year lag.

	Model 5 Twin transition t-1	Model 6 Twin transition t-1	Model 7 Twin transition t-1	Model 8 Twin transition t-1
EQI	2.740***			
	(0.700)			
Administrative efficiency		2.821***		
		(0.652)		
Impartiality			2.389***	
			(0.660)	
Control of corruption				3.452***
				(1.043)
GDP	9.82e−05***	9.63e−05***	0.000101***	−0.000136***
	(1.15e−05)	(1.14e−05)	(1.18e−05)	(2.09e−05)
HTEC	−0.0319*	−0.0293*	−0.0354**	0.250***
	(0.0167)	(0.0167)	(0.0171)	(0.0310)
Innovation index	0.123***	0.125***	0.133***	0.817***
	(0.0295)	(0.0277)	(0.0284)	(0.0271)
Other controls	YES	YES	YES	YES
	(0.0245)	(0.0230)	(0.0238)	(0.0226)
Sigma u	4.770***	4.713***	4.980***	17.46***
	(0.242)	(0.239)	(0.258)	(1.009)
Sigma e	7.415***	7.419***	7.405***	7.163***
	(0.145)	(0.146)	(0.145)	(0.128)
	(2.586)	(2.494)	(2.527)	(2.438)
Wald test	668.42***	676.30***	652.52***	3186.33***
Observations	3536	3536	3536	3536
NUTS 2	221	221	221	221

Note: Standard errors in parentheses.
Source: Author's elaboration.
*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

This research specifically focuses on the effect of institutional quality in twin transition, recognizing institutions as key players to foster the digital and green future of regions. By employing a Tobit panel regression model on patent data across European NUTS2 regions, we have shown that higher institutional quality, as measured by the EQI, is strongly associated with a greater output of twin transition patents, confirming findings from previous studies on the role of institutional quality and innovation (Rodríguez-Pose and Zhang 2020; Rodríguez-Pose and Di Cataldo 2015; Tebaldi and Elmslie (2013), and green innovation (Pinate et al. 2025; Chen et al. 2024).

First, at the more general level, our results show that there exists a positive and statistically significant relationship between the EQI and twin transition patenting confirming previous theoretical and empirical research emphasizing that institutions act as critical enablers of innovation (Pinate et al. 2025; Zhang and Rodríguez-Pose 2024, D'Ingiullo and Evangelista 2020), especially in times of systemic change. These results reinforce the idea that well-functioning institutions contribute significantly to innovation capacity by providing a stable and transparent regulatory environment, efficient public administration, and equitable treatment of individuals and firms. The robustness of this relationship, even when controlling for GDP, human capital in high-tech sectors, and regional innovation performance, highlights institutional quality not merely as a complementary factor but as a central component of the innovation ecosystem required for a successful twin transition.

Second, the different dimensions of the EQI, such as administrative efficiency, impartiality, and corruption control, also confirm these results. For instance, regions with efficient and responsive public services may reduce bureaucratic burdens, making it easier for firms to navigate regulatory landscapes and focus on developing and deploying novel technologies (Rodríguez-Pose and Zhang 2020; North 1990). Similarly, fair and impartial governance helps ensure equitable access to support systems, grants, and networks, which can strengthen collaboration and trust among innovation stakeholders (Zhang and Rodríguez-Pose 2024; Rodríguez-Pose and Di Cataldo 2015). Meanwhile, the importance of corruption control echoes the findings of previous literature (e.g., Pinate et al. 2025), suggesting that reducing uncertainty and improving institutional trust are vital for long-term innovation investments.

Furthermore, this study contributes to the growing body of research on the geography of the twin transition (Faggian et al. 2025), by evidencing the uneven spatial distribution of green-digital innovation across the EU. Core industrial regions,

TABLE 6 | Robustness test—inventors' address.

	Model 9 Inventors t-1	Model 10 Inventors t-1	Model 11 Inventors t-1	Model 12 Inventors t-1	Model 13 Inventors t-2	Model 14 Inventors t-2	Model 15 Inventors t-2	Model 16 Inventors t-2
EQI	1.341**				1.470***			
	(0.527)				(0.556)			
Administrative efficiency		1.427***				1.339***		
		(0.493)				(0.518)		
Impartiality			1.093**				1.177**	
			(0.481)				(0.508)	
Control of corruption				0.679				0.937**
				(0.451)				(0.473)
GDP	8.45e−05***	8.40e−05***	8.51e−05***	8.39e−05***	0.000104***	0.000103***	0.000104***	0.000103***
	(0.00000962)	(0.00000962)	(0.00000965)	(0.00000959)	(0.0000106)	(0.0000106)	(0.0000106)	(0.0000106)
HTEC	−0.0380***	−0.0371***	−0.0391***	−0.0403***	−0.0499***	−0.0497***	−0.0512***	−0.0519***
	(0.0137)	(0.0138)	(0.0138)	−0.0137	−0.0148	−0.0148	−0.0148	−0.0147
Innovation index	0.101***	0.0998***	0.108***	0.118***	0.101***	0.105***	0.109***	0.115***
	(0.0184)	(0.0176)	(0.0174)	(0.0169)	(0.0194)	(0.0186)	(0.0184)	(0.0178)
Other controls	YES	YES	YES	YES	YES	YES	YES	YES
Constant	−23.10***	−22.96***	−23.78***	−24.53***	−24.60***	−24.90***	−25.36***	−25.76***
	(1.867)	(1.815)	(1.785)	−1.775	−1.97	−1.921	−1.89	−1.864
Sigma u	4.460***	4.465***	4.501***	4.420***	4.896***	4.899***	4.941***	4.853***
	(0.323)	(0.324)	(0.326)	(0.32)	(0.354)	(0.354)	(0.357)	(0.352)
Sigma e	5.656***	5.646***	5.655***	5.672***	5.967***	5.963***	5.965***	5.981***
	(0.123)	(0.123)	(0.123)	(0.123)	(0.126)	(0.126)	(0.126)	(0.126)
Wald test	726.77***	729.89***	723.18***	726.47***	768.51***	770.64***	765.32***	769.39***
Observations	3536	3536	3536	3536	3536	3536	3536	3536
NUTS 2	221	221	221	221	221	221	221	221

Note: Standard errors in parentheses.
Source: Author's elaboration.
*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

particularly in Central and Northern Europe, dominate in patenting activity, whereas peripheral regions remain marginal players. This raises critical concerns about spatial inequality in the access to and benefits from the twin transition.

From a policy perspective, it clearly emerges that institutional quality does not merely serve as a background condition but acts as a dynamic enabler of innovation processes. Efficient and impartial public administrations can streamline bureaucratic procedures, enhance access to public support schemes, and foster trust-based collaboration between public and private actors. Conversely, corruption and institutional inefficiencies introduce uncertainty and inhibit both public and private investment in transformative technologies.

At the same time, while our results indicate that higher institutional quality is systematically associated with stronger green–digital inventive activity, they should not be interpreted as implying that institutions alone shield regions from polarisation or development traps. Rather, the findings point to a conditional and context-dependent role of governance. First, the absence of explicit interaction terms between institutional quality and development-trap status means that our empirical models cannot directly test heterogeneous effects across different regional trajectories. Second, descriptive evidence suggests the existence of cross-over cases—regions with relatively high institutional quality and income levels but modest twin-transition patenting performance—echoing the "unequal but successful" or "institutionally strong yet innovation-lagging" territories identified by Rodríguez-Pose et al. (2023). These cases highlight that institutional quality is a necessary but not sufficient condition for joint green–digital innovation, whose emergence also depends on complementary assets such as industrial structure, related knowledge bases, and mission-oriented policy coordination. From a policy perspective, this underscores the need for place-sensitive interventions: EU cohesion and recovery funding would be most effective if aligned not only with innovation objectives but also with region-specific institutional diagnostics. Strengthening administrative capacity, reducing corruption, and enhancing policy coordination in lagging regions may unlock latent innovation potential, while in institutionally strong but underperforming regions, funding could prioritize mechanisms that foster cross-sectoral knowledge recombination and strategic alignment between green and digital priorities. In this sense, institutional quality should be seen less as a universal shield against polarisation and more as a lever whose effectiveness depends on regional context and complementary capabilities.

The study is not without limitations. Institutional quality is a complex and multidimensional concept (Rodríguez-Pose 2020). The metrics used may not capture all relevant facets, especially when informal institutions are concerned, such as public trust, social capital, or civic norms. Although the EQI represents one of the most comprehensive subnational measures available, it is based on survey waves and therefore requires interpolation to construct annual series, which may smooth short-term fluctuations in institutional conditions.

From an econometric perspective, we adopt a conservative modeling strategy that prioritizes internal coherence between the data-generating process and the econometric specification. The empirical strategy is designed to mitigate reverse causality by adopting a forward-looking structure and extensive controls. The censored nature of patent data and the large share of zero observations motivate the use of a panel Tobit specification, but at the same time constrain the applicability of alternative identification strategies, such as instrumental-variable, dynamic panel, or quasi-experimental approaches. Future research could explore causal mechanisms more explicitly when richer data or alternative outcome measures allow for different modeling strategies.

In addition, future research could explicitly investigate spatial spill-overs and interregional diffusion mechanisms in the spread of green–digital innovation. Spatial interactions are likely to play an important role in shaping regional innovation trajectories, and dedicated research designs (possibly based on longer time series or alternative innovation indicators) would allow for a more detailed analysis of diffusion processes across neighboring regions.

The geographical focus on European NUTS-2 regions further limits the external validity of the findings. Extending the analysis to regions outside Europe, or to contexts characterized by different institutional architectures, could help assess the generalisability of the results. Similarly, although patents represent a well-established proxy for technological innovation, future research could integrate additional indicators (such as scientific publications, R&D investments, or technology adoption measures) to capture a broader range of innovation dynamics associated with the twin transition.

Finally, a deeper qualitative investigation into the mechanisms through which institutional quality shapes twin-transition innovation (through case studies, interviews, or policy analysis) would help open the current "black box" and complement the quantitative evidence. Such approaches could also better capture the role of informal institutions and governance practices, which may be particularly relevant when the twin transition is examined in relation to regional development traps and the geography of discontent.

Endnotes

[1] IQI is composed by five specific dimensions: "regulatory quality," "voice and accountability," "government effectiveness," "rule of law," and "corruption."

References

Acemoglu, D., and S. Johnson. 2005. "Unbundling Institutions." *Journal of Political Economy* 113, no. 5: 949–995.

Agerberg, M. 2017. "Failed Expectations: Quality of Government and Support for Populist Parties in Europe." *European Journal of Political Research* 56, no. 3: 578–600.

Apergis, N., and M. Pinar. 2023. "Corruption and Partisan Polarization: Evidence From the European Union." *Empirical Economics* 64, no. 1: 277–301.

Appiah, M., S. Karim, M. A. Naeem, and B. M. Lucey. 2022. "Do Institutional Affiliation Affect the Renewable Energy-Growth Nexus in the Sub-Saharan Africa: Evidence From a Multi-Quantitative Approach." *Renewable Energy* 191: 785–795.

Asheim, B. T., H. L. Smith, and C. Oughton. 2011. "Regional Innovation Systems: Theory, Empirics and Policy." *Regional Studies* 45, no. 7: 875–891.

Bănică, A., R. Ţigănaşu, P. Nijkamp, and K. Kourtit. 2024. "Institutional Quality in Green and Digital Transition of EU Regions—A Recovery and Resilience Analysis." *Global Challenges* 8, no. 9: 2400031.

Barbero, J., L. A. Collado, E. Rodríguez-Crespo, and A. M. Santos. 2025. "The Twin Transition in the European Union: Assessing Regional Patterns of EU-Funded Investments." *European Planning Studies* 33: 1801–1821.

Barbieri, N., F. Perruchas, and D. Consoli. 2020. "Specialization, Diversification, and Environmental Technology Life Cycle." *Economic Geography* 96, no. 2: 161–186.

Bianchini, S., G. Damioli, and C. Ghisetti. 2023. "The Environmental Effects of the "Twin" Green and Digital Transition in European Regions." *Environmental and Resource Economics* 84, no. 4: 877–918.

Boschma, R. 2005. "Proximity and Innovation: A Critical Assessment." *Regional Studies* 39, no. 1: 61–74.

Boschma, R. A., and K. Frenken. 2006. "Why Is Economic Geography Not an Evolutionary Science? Towards an Evolutionary Economic Geography." *Journal of Economic Geography* 6, no. 3: 273–302.

Boschma, R., and K. Frenken. 2018. "Evolutionary Economic Geography." In *The New Oxford Handbook of Economic Geography*, 213–229. Oxford University Press.

Boschma, R., and R. Martin. 2007. "Editorial: Constructing An Evolutionary Economic Geography." *Journal of Economic Geography* 7, no. 5: 537–548.

Boschma, R., and R. Martin. 2010. *The Handbook of Evolutionary Economic Geography*. Edwarg Elgar.

Bottasso, A., G. Cerruti, and M. Conti. 2022. "Institutions Matter: The Impact of the Covid-19 Pandemic on the Political Trust of Young Europeans." *Journal of Regional Science* 62, no. 4: 1122–1148.

Boudreaux, C. J. 2017. "Institutional Quality and Innovation: Some Cross-Country Evidence." *Journal of Entrepreneurship and Public Policy* 6, no. 1: 26–40.

Bourdin, S., and A. Torre. 2023. "Geography of Contestation: A Study on the Yellow Vest Movement and the Rise of Populism in France." *Journal of Regional Science* 63, no. 1: 214–235.

Brueck, C., S. Losacker, and I. Liefner. 2025. "China's Digital and Green (Twin) Transition: Insights From National and Regional Innovation Policies." *Regional Studies* 59, no. 1: 2384411.

Butenko, A., and P. Larouche. 2015. "Regulation for Innovativeness or Regulation for Innovation?" *Law, Innovation and Technology* 7, no. 1: 52–82.

Capello, R. 2002. "Entrepreneurship and Spatial Externalities: Theory and Measurement." *The Annals of Regional Science* 36, no. 3: 387–402.

Charron, N., L. Dijkstra, and V. Lapuente. 2014. "Regional Governance Matters: Quality of Government Within European Union Member States." *Regional Studies* 48, no. 1: 68–90.

Charron, N., V. Lapuente, and P. Annoni. 2019. "Measuring Quality of Government in EU Regions Across Space and Time." *Papers in Regional Science* 98, no. 5: 1925–1954.

Chen, C., M. Pinar, and R. Roman-Collado. 2024. "Green Innovation and Energy Efficiency: Moderating Effect of Insitutional Quality Based on the Threshold Model." *Environmental and Resource Economics* 87, no. 12: 3063–3094.

Collini, L., and P. Hausemer. 2024. "Place-Based Pathways for the Twin Transition: The Role of Systemic Change Agents." *Competitiveness Review: An International Business Journal* 34, no. 5: 864–878.

Cooke, P. 2008. "Regional Innovation Systems: Origin of the Species." *International Journal of Technological Learning, Innovation and Development* 1, no. 3: 393–409.

Cooke, P., M. Gomez Uranga, and G. Etxebarria. 1997. "Regional Innovation Systems: Institutional and Organisational Dimensions." *Research Policy* 26, no. 4–5: 475–491.

Crescenzi, R., and A. Rodriguez-Pose. 2011. *Innovation and Regional Growth in the European Union*. Springer Science & Business Media.

Crescenzi, R., and A. Rodríguez-Pose. 2009. "Systems of Innovation and Regional Growth in the EU: Endogenous vs. External Innovative Activities and Socio-Economic Conditions." In *Growth and Innovation of Competitive Regions: The Role of Internal and External Connections*, 167–191. Springer.

Culas, R. J. 2007. "Deforestation and the Environmental Kuznets Curve: An Institutional Perspective." *Ecological Economics* 61, no. 2–3: 429–437.

Cutrini, E. 2023. "Postcrisis Recovery in the Regions of Europe: Does Institutional Quality Matter?" *Journal of Regional Science* 63, no. 1: 5–29.

D'Ingiullo, D., and V. Evangelista. 2020. "Institutional Quality and Innovation Performance: Evidence From Italy." *Regional Studies* 54, no. 12: 1724–1736.

Dam, M. M., C. Isik, and S. Ongan. 2023. "The Impact of Renewable Energy and Institutional Quality in Environmental Sustainability in the Context of the Sustainable Development Goals: A Novel Approach With the Inverted Load Capacity Factor." *Environmental Science and Pollution Research* 30, no. 42: 95394–95409.

Damioli, G., S. Bianchini, and C. Ghisetti. 2025. "The Emergence of a 'Twin Transition' Scientific Knowledge Base in the European Regions." *Regional Studies* 59, no. 1: 2355998.

De Pascale, G., A. Pronti, and R. Zoboli. 2024. "The Role of Local Institutional Quality for the Digital and Environmental Transitions in Italy." *Structural Change and Economic Dynamics* 71: 689–705.

De Ruyter, A., R. Martin, and P. Tyler. 2021. "Geographies of Discontent: Sources, Manifestations and Consequences." *Cambridge Journal of Regions, Economy and Society* 14, no. 3: 381–393.

Diemer, A., S. Iammarino, A. Rodríguez-Pose, and M. Storper. 2022. "The Regional Development Trap in Europe." *Economic Geography* 98, no. 5: 487–509.

Dijkstra, L., H. Poelman, and A. Rodríguez-Pose. 2020. "The Geography of EU Discontent." *Regional Studies* 54, no. 6: 737–753.

Edquist, C. 1997. "Introduction." In *Systems of Innovation Technologies, Institutions and Organisations*, 1–5. Routledge.

Faggian, A., A. Marzucchi, and S. Montresor. 2025. "Regions Facing the 'Twin Transition': Combining Regional Green and Digital Innovations." *Regional Studies* 59, no. 1: 2398555.

Fazio, G., S. Maioli, and N. Rujimora. 2025. "The Twin Innovation Transitions of European Regions." *Regional Studies* 59, no. 1: 2309176.

Ferrante, C., and N. Pontarollo. 2022. "The Populist Outbreak and the Role of Institutional Quality in European Regions." *Scienze Regionali* 22, no. 3: 337–366.

Filip, M. D., and R. Setzer. 2025. The Impact of Regional Institutional Quality on Economic Growth and Resilience in the EU (No. 3045). ECB Working Paper.

Florida, R. 2021. "Discontent and its Geographies." *Cambridge Journal of Regions, Economt and Society* 14, no. 3: 619–624.

Geels, F. W., J. Pinkse, and D. Zenghelis. 2021. *Productivity Opportunities and Risks in a Transformative, Low-Carbon and Digital Age*. The Productivity Institute. Working Paper 9.

Greve, M., M. Fritsch, and M. Wyrwich. 2023. "Long-Term Decline of Regions and the Rise of Populism: The Case of Germany." *Journal of Regional Science* 63, no. 2: 409–445.

Guarascio, D., J. Reljic, and A. Simonazzi. 2026. "United in Diversity? EU Core-Periphery Divides at the Time of the Green Transition." *Governance* 39, no. 1: e70089.

Horbach, J., Q. Chen, K. Rennings, and S. Vögele. 2014. "Do Lead Markets for Clean Coal Technology Follow Market Demand? A Case

Study for China, Germany, Japan and the US." *Environmental Innovation and Societal Transitions* 10: 42–58.

Karahasan, B. C., and M. Pinar. 2024. "Institutional Quality and Geography of Discontent in the EU." *JCMS: Journal of Common Market Studies* 62, no. 6: 1712–1733.

Kinyar, A., and K. Bothongo. 2024. "The Impact of Renewable Energy, Eco-Innovation, and GDP Growth on CO2 Emissions: Pathways to the UK's Net Zero Target." *Journal of Environmental Management* 368: 122226.

Kogler, D. F. 2015. "Editorial: Evolutionary Economic Geography—Theoretical and Empirical Progress." *Regional Studies* 49, no. 5: 705–711.

Lasagni, A., A. Nifo, and G. Vecchione. 2015. "Firm Productivity and Institutional Quality: Evidence From Italian Industry." *Journal of Regional Science* 55, no. 5: 774–800.

Leggerini, C., M. Bannò, and M. Dal Molin. 2025. "Hydrogen Innovation: An Exploration of Its Determinants Across Europe." *Energy Policy* 204: 114675.

Lenzi, C., and G. Perucca. 2021. "People or Places That Don't Matter? Individual and Contextual Determinants of the Geography of Discontent." *Economic Geography* 97, no. 5: 415–445.

Levchenko, A. A. 2007. "Institutional Quality and International Trade." *Review of Economic Studies* 74, no. 3: 791–819.

Losacker, S., J. Horbach, and I. Liefner. 2023. "Geography and the Speed of Green Technology Diffusion." *Industry and Innovation* 30, no. 5: 531–555.

Maraut, S., H. Dernis, C. Webb, V. Spiezia, and D. Guellec, 2008. *The OECD REGPAT Database: A Presentation*. OECD Publishing. OECD Science, Technology and Industry Working Papers 2008/2.

Marrocu, E., R. Paci, and L. Serafini. 2025. *Smart and Green. The Uneven Effects of the Twin Transition in European Regions (202510)*. Centre for North South Economic Research, University of Cagliari and Sassari.

Martinelli, A., A. Mina, and M. Moggi. 2021. "The Enabling Technologies of Industry 4.0: Examining the Seeds of the Fourth Industrial Revolution." *Industrial and Corporate Change* 30, no. 1: 161–188.

McCann, P. 2020. "Perceptions of Regional Inequality and the Geography of Discontent: Insights From the UK." *Regional Studies* 54, no. 2: 256–267.

Nafeza, E., A. N. Raj, and M. P. Sudharani. 2025. "Impartiality and Innovation: The Role of Bureaucratic Neutrality in Facilitating Digital Technology Integration in the Modern Era." *International Journal of Research in Management* 15: 17–23.

Nasir, M. H., and S. Zhang. 2024. "Evaluating Innovative Factors of the Global Innovation Index: A Panel Data Approach." *Innovation and Green Development* 3, no. 1: 100096.

Nifo, A., and G. Vecchione. 2014. "Do Institutions Play a Role in Skilled Migration? The Case of Italy." *Regional Studies* 48, no. 10: 1628–1649.

North, D. C. 1990. *Institutions, Institutional Change and Economic Performance*. Cambridge University Press.

Obobisa, E. S., H. Chen, and I. A. Mensah. 2022. "The Impact of Green Technological Innovation and Institutional Quality on CO_2 Emission in African Countries." *Technological Forecasting and Social Change* 180: 121670.

Ortega, A. M., and M. Serna. 2020. "Determinants of Innovation Performance of Organizations in a Regional Innovation System From a Developing Country." *International Journal of Innovation Science* 12, no. 3: 345–362.

Pasimeni, F., A. Fiorini, and A. Georgakaki. 2021. "International Landscape of the Inventive Activity on Climate Change Mitigation Technologies. A Patent Analysis." *Energy Strategy Reviews* 36: 100677.

Pike, A., A. Rodríguez-Pose, and J. Tomaney. 2016. *Local and Regional Development*. Routledge.

Pinate, A. C., M. Dal Molin, and M. G. Brandano. 2025. *Institutional Quality and Green Innovation in Italy: A Regional Perspective (No. 202508)*. Centre for North South Economic Research, University of Cagliari and Sassari.

Pinate, A., L. Cattani, M. Dal Molin, and A. Faggian. 2024. "'Get Back to Where You Once Belonged'? Effects of Skilled Internal Migration on Italian Regional Green Growth." *Papers in Regional Science* 103, no. 4: 100036.

Rahman, M. M., and N. Sultana. 2022. "Impacts of Institutional Quality, Economic Growth and Exports on Renewable Energy: Emerging Countries Perspective." *Renewable Energy* 189: 938–951.

Rodriguez-Pose, A., and M. Di Cataldo. 2015. "Quality of Government and Innovative Performance in the Regions of Europe." *Journal of Economic Geography* 15, no. 4: 673–706.

Rodriguez-Pose, A., and M. Zhang. 2020. "The Cost of Weak Institutions for Innovation in China." *Technological Forecasting and Social Change* 153: 119937.

Rodriguez-Pose, A., J. Terrero-Davila, and N. Lee. 2023. "Left-Behinf Versus Unequal Places: Interpersonal Inequality, Economic Decline and the Rise of Populism in the USA and Europe." *Journal of Economic Geography* 23, no. 5: 951–977.

Rodríguez-Pose, A. 2013. "Do Institutions Matter for Regional Development?" *Regional Studies* 47, no. 7: 1034–1047.

Rodríguez-Pose, A. 2018. "The Revenge of the Places That Don't Matter (and What to Do About It)." *Cambridge Journal of Regions, Economy and Society* 11, no. 1: 189–209.

Rodríguez-Pose, A. 2020. "Institutions and the Fortunes of Territories." *Regional Science Policy & Practice* 12, no. 3: 371–386.

Rodríguez-Pose, A., and E. M. Villarreal Peralta. 2015. "Innovation and Regional Growth in Mexico: 2000–2010." *Growth and Change* 46, no. 2: 172–195.

Rodríguez-Pose, A., and F. Bartalucci. 2024. "The Green Transition and Its Potential Territorial Discontents." *Cambridge Journal of Regions, Economy and Society* 17, no. 2: 339–358.

Rodríguez-Pose, A., and M. Storper. 2006. "Better Rules or Stronger Communities? On the Social Foundations of Institutional Change and Its Economic Effects." *Economic Geography* 82, no. 1: 1–25.

Roessler, M. 2024. "Untangling Regional Development Traps Through Narratives." *Regional Studies, Regional Science* 11, no. 1: 406–418.

Santos, A., J. Edwards, and P. Neto. 2023. "Does Smart Specialisation Improve any Innoivation Subsidy Effect on Regional Productivity? The Portuguese Case." *European Planning Studies* 31, no. 4: 758–779.

Shrestha, S. L. 2022. "Quantifying Effects of Meteorological Parameters on Air Pollution in Kathmandu Valley Through Regression Models." *Environmental Monitoring and Assessment* 194, no. 10: 684.

Storper, M. 2018. "Regional Innovation Transitions." In *Knowledge and Institutions: Knowledge and Space*, edited by In. J. Glückler, R. Suddaby and R. Lenz, 197–225. Springer.

Sun, H., B. K. Edziah, C. Sun, and A. K. Kporsu. 2019. "Institutional Quality, Green Innovation and Energy Efficiency." *Energy Policy* 135: 111002.

Sundström, A., and L. Wängnerud. 2018. "Women's Empowerment at the Local Level." In *Measuring Women's Political Empowerment Across the Globe*, edited by A. C. Alexander, C. Bolzendahl and F. Jalalzai, 117–137. Springer International Publishing.

Tal, M., R. Lavi, S. Reiss, and Y. J. Dori. 2024. "Gender Perspectives on Role Models: Insights From STEM Students and Professionals." *Journal of Science Education and Technology* 33: 699–717.

Tebaldi, E., and B. Elmslie. 2013. "Does Institutional Quality Impact Innovation? Evidence From Cross-Country Patent Grant Data." *Applied Economics* 45, no. 7: 887–900.

Torre, A., and S. Bourdin. 2026. “Geography of Discontent and Beyond: Extreme Voting, Protestations, Riots and Violence, and Their Spatial Content.” *Regional Science Policy & Practice* 18, no. 1: 100272.

Wooldridge, J. M. 2019. *Introductory Eeconometrics.* Cengage.

Zhang, M., and A. Rodríguez-Pose. 2024. “Government Reform and Innovation Performance in China.” *Papers in Regional Science* 103, no. 3: 100023.