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Decoding regional dynamics: Institutions, innovation, and regional development in the EU

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ABSTRACT

The importance of institutions and innovation for regional development is well established. How these two factors interact under different historical legacies and urban-regional contexts remains, however, insufficiently understood. This paper identifies which combinations of institutional and innovation indicators most effectively classify regions into distinct developmental archetypes, revealing critical thresholds that redirect regional trajectories. Employing decision-tree analysis on 233 EU NUTS-2 regions, we analyse 15 indicators spanning institutional quality, technological readiness, business sophistication, and innovation. This methodology uncovers non-linear relationships that traditional approaches cannot capture. The findings demonstrate that institutional quality acts as a necessary condition for innovation-led growth. High-performing regions, predominantly in Western and Northern Europe, benefit from robust institutions and strong innovation outputs. Many lower-performing regions, particularly in Central and Eastern Europe, exhibit innovation potential but are constrained by governance deficits. By integrating institutional and innovation indicators within a single analytical framework, we underscore how addressing governance and innovation in tandem can result in balanced and sustainable growth across Europe.

1. Introduction

The second half of the twentieth century delivered a transformation as profound as any before it. The shift from industrial society to information age introduced sweeping changes in technology, economics, and institutions, all fuelled by rapid advances in information technology. This digital revolution, comparable to the agrarian and industrial revolutions, reshaped the global economy and forced a stark choice on regions: adapt and innovate or face stagnation and decline.

Regions are no longer passive instruments of state policy. They have emerged as proactive agents within multi-level governance systems. Endogenous development theory (Vázquez-Barquero, 2002; Capello and Nijkamp, 2011; Todaro and Smith, 2011; Todaro and Smith, 2020) reinforces this shift by highlighting the critical role of localised factors such as human capital, innovation capacity, and institutional quality in driving economic processes and fostering regional competitiveness. Endogenous growth models (Frankel, 1962; Lucas, 1988; Stokey and Rebelo, 1995) likewise posit that human and intellectual capital are fundamental for technological progress, challenging the exogenous assumptions of neoclassical growth theory (Solow, 1956; Swan, 1956). Mechanisms like learning-by-doing and R&D investment spur long-term growth (Aghion et al., 1998). Later work (Mankiw et al., 1992; Howitt, 2000) incorporates institutional diversity and technology transfer, showing that regions with supportive governance and innovation policies can achieve sustained growth.

The literature converges on several key insights. First, industrial clusters (Porter, 1998) and regional innovation systems (Cooke et al., 1997; Asheim et al., 2011) provide further insight into how institutions and innovation together drive regional development. Institutions set the "rules of the game" (North, 1990), governing economic activities by enabling knowledge dissemination, fostering collaboration, and reducing uncertainty (Freeman, 1987; Edquist, 2001). Regions with

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robust institutions are better equipped to integrate diverse actors and resources, creating environments conducive to innovation and entrepreneurship. Second, strong institutional frameworks (e.g. effective public services, rule of law, and high control of corruption) build trust and lower transaction costs, thereby enhancing innovative activity (Gertler, 2010; Rodríguez-Pose, 2013). In turn, vibrant innovation ecosystems, characterised by knowledge generation, skilled human capital, and dynamic firms, increase the returns on good governance by driving productivity and diversification (Boschma and Frenken, 2011; Schwab, 2017).

Regional development has thus become a contest over competitiveness. Success depends on boosting productivity, attracting skilled workers, fostering innovative firms, and raising living standards (Florida, 2002; Bristow, 2005). The concept integrates economic, social, and institutional dimensions. Policymakers operationalise this through indices such as the EU Regional Competitiveness Index (RCI). The RCI 2022 analysis reveals that disparities between EU regions are widest in innovation, with significant gaps in institutional quality. Peripheral regions in the EU, and mostly Central and Eastern European (CEE) regions, tend to suffer especially large deficits in innovation capacity and governance, highlighting the importance of studying these pillars together. At the same time, there are signs of convergence: many CEE regions have improved their competitiveness in recent years (Giannini and Martini, 2024), though they still trail the EU average (Annoni and Dijkstra, 2019; Dijkstra et al., 2023). National and regional policies like smart specialisation strategies have sought to leverage local strengths for innovation (Foray et al., 2012; European Commission, 2014), but their success still depends on parallel institutional improvements (Rodríguez-Pose and Ketterer, 2020).

Despite extensive research on institutions and innovation individually, their combined influence on regional outcomes, especially in the context of Europe's diverse institutional legacies, remains poorly understood. The historical divide between Western Europe and post-socialist CEE persists in both institutional and innovation disparities (Rodríguez-Pose and Di Cataldo, 2015; Camagni et al., 2020), meaning that three questions demand answers: Do strong institutions consistently underpin innovation and development? Can innovation flourish where governance is weak? How do regions with similar profiles cluster across Europe's development spectrum?

To answer these questions, we pursue three objectives. First, establish the relationship between institutional quality and innovation capacity in shaping competitiveness. Second, examine how historical legacies and urban-regional contexts (particularly capital cities) condition these relationships. Third, identify discernible regional groupings and their implications for development trajectories.

Our approach differs from prior research. We employ machine-learning-based decision tree (CART) analysis to capture complex, non-linear interactions that linear models miss. While others have used panel regressions or composite indices (e.g., Rodríguez-Pose, 2013; Moirangthem and Nag, 2022), we segment regions into homogenous groups based on institutional and innovation attributes, revealing distinct "archetypes" and the critical thresholds in indicators that differentiate development outcomes.

The contributions are threefold. First, we integrate institutional and innovation metrics within a single framework, examining interaction effects. This is something that prior research has called for but rarely delivered (Tödtling and Trippl, 2005). We extend work on institutions in development (North, 1990; Acemoglu et al., 2005) and regional innovation systems (Cooke, 2001; Asheim et al., 2011). Second, our application of CART modelling to regional development is novel. This method (Breiman et al., 1984) uncovers non-linear patterns and identifies thresholds where trajectories change. This allows us to provide a more granular classification of regions into distinct archetypes based on their governance and innovation capacities, offering insights that conventional regression-based methods or composite indices cannot reveal. Third, we introduce contextual differentiation, explicitly considering how historical legacies and urban structures condition the institutions-innovation relationship, shifting debate from "institutions and innovation matter" towards understanding *how* they matter within specific contexts.

The evidence shows historically underperforming regions can catch up through institutional improvement, corroborating recent findings that strengthening governance yields tangible dividends (e.g., Rodríguez-Pose and Ketterer, 2020; Filip and Setzer, 2025). Overall, our analysis bridges empirical evidence with policy insight, underscoring that sustained development is an iterative process driven by interlinked improvements in institutions and innovation.

The remainder of the paper proceeds as follows. 2 reviews the theoretical foundations. 3 describes the data and methodology. 4 presents the results: relationships between indicators (4.1) and comparative analysis through decision tree modelling (4.2). 5 discusses the findings, while 6 concludes.

2. Institutions and innovation In regional development

When regions succeed, their residents prosper. Effective development involves targeted policies to stimulate growth, upgrade infrastructure, invest in human capital, and address social challenges. Properly implemented, such strategies reduce disparities, create employment, and nurture local innovation (European Commission, 2010; Carayannis and Rakhmatullin, 2014; Karlsson et al., 2019; Capello et al., 2020). By prioritising investment in underperforming regions, governments can build more balanced and resilient national economies, improving quality of life and economic stability across the board (Reggiani et al., 2002; Christopherson et al., 2010; Pike et al., 2016; World Bank, 2021).

In recent years, regional competitiveness has emerged as the dominant framework. It captures a region's capacity to offer an attractive, sustainable environment for firms and residents, by achieving high productivity, employing skilled workers, generating innovation, and, consequently, delivering high living standards (Porter, 1998; Bristow, 2005). According to Cooke (2004) and Bristow (2005), this integrates economic factors (infrastructure, market efficiency), innovative capacity (technology, R&D, entrepreneurship), human capital (skills, education), and institutional quality (governance, public services). Excellence in one or two dimensions proves insufficient; balanced improvements across multiple pillars reinforce each other (Annoni and Dijkstra, 2019), resulting in stronger economic progress. Recent analyses stress that simultaneous gains in several areas, not excellence in just one, drive a more robust performance.

Within this competitiveness framework, institutional quality has gained recognition as a fundamental driver of regional development (Rodríguez-Pose, 2013; Ketterer and Rodríguez-Pose, 2018; Caragliu and Del Bo, 2025). Institutions, defined broadly as the formal and informal "rules" governing economic and social interactions (North, 1990), shape the business environment and influence the efficiency with which resources are allocated. High-quality institutions are characterised by transparent and accountable governance, high control of corruption, impartial rule of law, and effective public services (Rodríguez-Pose and Di Cataldo, 2015). Such conditions build investor confidence, encourage entrepreneurship, and ensure that public investments (e.g. in education or infrastructure) yield results. By contrast, weak institutions can stifle development: insufficient control of corruption, bureaucratic inefficiency, or insecure property rights deter innovation and investment, leading to talent drain and misallocation of resources (Rodrik et al., 2004). Empirical studies confirm the impact of institutions on regional outcomes. For example, Filip and Setzer (2025) show that improving a low-income region's institutional quality to the EU median could raise its GDP per capita growth by about 0.5 %age points annually. Additionally, quasi-experimental evidence based on early adopters of government reform in China demonstrates that improvements in institutional quality significantly enhance regional

innovation, particularly in medium- and upper-tier innovative regions (Zhang and Rodríguez-Pose, 2024). Together, these findings underscore that institutional reforms, such as enhancing public sector efficiency or increasing control of corruption, can spur convergence and resilience in lagging areas.

Innovation capacity remains equally critical. Endogenous growth theory positions innovation —new technologies, products, processes— as the primary source of productivity improvements and long-run growth (Aghion et al., 1998). Regions with vibrant innovation ecosystems normally feature higher R&D expenditure, more patents, more scientific publications, a knowledge-rich workforce, and firms that continuously upgrade (Cooke et al., 1997; Asheim et al., 2011). These factors drive performance directly. Regions with strong innovation outputs generally enjoy higher GDP per capita and growth rates (Fagerberg and Srholec, 2008; Capello and Lenzi, 2013).

Yet the relationship is bidirectional. Innovation thrives where preconditions —human capital, infrastructure, institutional support— exist (Rodríguez-Pose and Crescenzi, 2008). Effective institutions facilitate innovation through education, research support, rule of law. Innovation, in turn, pressures or provides resources for institutional improvement as economies become more complex and demand better governance.

Europe's historical legacies created considerable heterogeneity. Western and Northern regions benefited from centuries of stable institutions and steady innovation investments. CEE regions underwent abrupt 1990s transitions from planned to market economies, with institutional rebuilding still ongoing. Significant gaps persist: post-socialist regions have lower government quality and lag their Western counterparts (Charron et al., 2022). The RCI 2019 and 2022 editions show Eastern and some Southern regions scoring consistently lower on both the institutions and innovation pillars, though improvements have occurred (Annoni and Dijkstra, 2019; Dijkstra et al., 2023). Nearly all Member States see capital city regions outperform the rest, owing to concentrated resources and talent (Dijkstra et al., 2023).

This interplay of geography, history, and policy creates a complex landscape where different combinations of institutional and innovation strengths or weaknesses define distinct profiles. Understanding these profiles and pathways for change matters for theory (refining growth models) and policy (designing interventions).

Given the discussion above, we formulate three hypotheses:

- H_1 (Institutions → Competitiveness): Regions with higher quality institutions exhibit greater innovation capacity and stronger economic performance.
- H_2 (Innovation → Competitiveness): Regions with higher innovation inputs and outputs (R&D investment, patents, skilled workers) perform better economically.
- H_3 (Regional Heterogeneity): Historical and structural differences produce a core-periphery pattern: Western and Northern European regions combine high institutional quality and innovation, placing them amongst top performers; most CEE regions cluster as lower performers with deficits in one or both dimensions

3. Empirical strategy, data and methods

We combine traditional statistical analysis with decision-tree modelling to address our research questions. Using a CART (Classification and Regression Tree) algorithm (Breiman et al., 1984), we segment European regions based on institutional and innovation characteristics, identifying distinct developmental patterns. The approach captures non-linear interactions and threshold effects hypothesised earlier

3.1. Data and variables

Our dataset covers 233 NUTS-2 regions across all 27 EU member states. Variable selection follows the EU Regional Competitiveness Index (RCI) framework. The RCI, introduced in 2010 and updated every three years, has become the cornerstone of comparative regional analysis. Building on the Global Competitiveness Index methodology (Schwab and Porter, 2007), it evaluates regions across 11 pillars and dozens of indicators, offering a multidimensional view that extends well beyond conventional economic metrics. The RCI provides a longitudinal dataset encompassing 11 pillars and dozens of indicators related to Institutions, Macroeconomic stability, Infrastructure, Health, Basic education (basic sub-index), Higher education and long-life learning, Labour market efficiency, Market size (efficiency sub-index), Technological readiness, Business sophistication, and Innovation (innovation sub-index). Crucially, it integrates institutional quality and innovation capacity alongside productivity, infrastructure, and social dimensions, thereby capturing the interplay between governance structures and innovation ecosystems that shape long-term competitiveness (Annoni and Kozovska, 2010; Annoni and Dijkstra, 2013, 2019; Bocci et al., 2024). The breadth of coverage, coupled with methodological consistency across its editions, provides a robust and reliable longitudinal dataset, enabling rigorous analysis of both convergence and divergence across the EU's 233 regions. Unlike narrower economic indices, the RCI's comprehensiveness makes it especially suitable for examining regional dynamics driven by institutions and innovation within a unified framework (Aiginger and Firgo, 2017; Dijkstra et al., 2023).

We analyse 15 indicators at NUTS2 level, grouped into four pillars: Institutions and three Innovation sub-index pillars (Technological Readiness, Business Sophistication, Innovation). The indicators used in the analysis derive from Eurostat and European Commission databases, including the European Quality of Government Index survey for institutional measures. Table 1 provides an overview.

All 233 regions had complete information for these indicators. Some —especially institutional ones— are standardised to mean 0 and standard deviation 1 at EU level (Charron et al., 2014). We standardised other continuous indicators where appropriate, aiding interpretability of threshold values.

We divide regions into Western[1] versus CEE[2] categories, serving as our target variable. We also consider national capital presence as a contextual factor, given capitals' outsize role (Dijkstra et al., 2023). Table 2 summarises the regional breakdown.

By integrating these divisions with our decision-tree models, we aim to map how combinations of institutional and innovation characteristics align with regional development outcomes. In the next subsection, we describe the methodological steps of our analysis, which include preliminary statistical tests and the core decision-tree modelling.

3.2. Methodology

The main objective of this study is to identify which combinations of institutional and innovation indicators most effectively classify European regions into distinct developmental archetypes, thereby revealing the critical thresholds that redirect regional trajectories. To guide the analysis, we test three hypotheses: H1: regions with higher institutional quality achieve higher innovation capacity and stronger economic performance; H2: regions with higher innovation inputs and outputs perform better economically; and H3: regional heterogeneity persists, with Western and Northern Europe typically combining high institutional quality and innovation, while many Central and Eastern European regions lag behind due to institutional or innovation deficits. These hypotheses are operationalized through three research questions as

[1] Western regions include regions in Austria (8), Belgium (9), Cyprus (1), Denmark (5), Finland (5), France (27), Germany (37), Greece (13), Ireland (3), Italy (21), Luxembourg (1), Malta (1), Netherlands (11), Portugal (7), Spain (19), Sweden (8).

[2] CEE regions include regions in Bulgaria (6), Croatia (2), Czech Republic (7), Estonia (1), Hungary (7), Latvia (1), Lithuania (2), Poland (17), Romania (8), Slovakia (4), Slovenia (2).

Table 1
Institution and innovation indicators overview.

Pillar	Indicator	Description	Unit
Institutions	Control of Corruption	Index of control of corruption in public services (higher = less corruption)	z-score (higher=better)
Institutions	Quality of Government (QoG)	Index of quality and accountability in public services (higher = better quality)	z-score (higher=better)
Institutions	Impartiality	Index of impartiality in public services (higher = more impartial/fair)	z-score (higher=better)
Institutions	E-government Use	Individuals using internet to interact with public authorities (e.g., for forms, information)	% of individuals
Technological Readiness	Households with broadband	Households with broadband access (any speed)	% of households
Technological Readiness	Individuals shopping online	Individuals who ordered goods/services online in last 12 months	% of individuals
Technological Readiness	Access to high-speed broadband	Population with access to ≥ 100 Mbps broadband	% of population
Business Sophistication	Employment in K–N sectors	Employment in knowledge-intensive services (finance, real estate, professional & support services)	% of total employment
Business Sophistication	GVA in K–N sectors	Gross value added in knowledge-intensive service sectors	% of total GVA
Innovation	Total patent applications	Patent applications per million inhabitants	Number per million
Innovation	Scientific publications	Scientific publications per capita (fractional count)	Number per capita
Innovation	R&D expenditure	Total intramural R&D expenditure	% of GDP
Innovation	Human Resources in S&T (HRST)	Population with tertiary education or employed in S&T (% of active population)	% of active population
Innovation	Core creative class employment	Employment in creative occupations (% of population 15–64)	% of population (15–64)
Innovation	Knowledge workers	Employment in knowledge-intensive occupations (% of total employment)	% of total employment

Source: Dijkstra et al. (2023)

Table 2
Data on EU NUTS 2 regions.

	No. of regions	Capital Region	Others
Western regions	176	16	160
CEE regions	57	11	46
Total	233	27	207

depicts Fig. 1.

We first analyse correlations among institutional and innovation indicators using a Pearson correlation matrix visualised in a heatmap. To compare regional performance, we apply non-parametric tests (Wilcoxon and Kruskal-Wallis) across groups of regions defined by historical legacies and capital status. Finally, we employ CART decision-tree modelling to classify regions into homogeneous groups, highlighting the thresholds in institutional and innovation indicators that best explain divergent development trajectories. Under the CART methodology, each decision node represents the point at which the algorithm selects the optimal variable to maximise subgroup homogeneity. Variables can reappear at multiple levels of the tree, underscoring their recurrent importance in refining classifications. Recursive partitioning continues until subgroups reach a predefined level of purity, the sample size falls below a minimum threshold, or further splits fail to improve classification accuracy. At this stage, nodes become terminal, providing final classifications that reflect how institutional, or innovation indicators shape regional development trajectories (Breiman et al., 1984). Decision trees offer several advantages over traditional econometric approaches. They are non-parametric and require no assumptions about data distribution; they handle multidimensional and interdependent variables, reflecting the complexity of regional economies; and they produce interpretable "if–then" rules that make results accessible to both scholars and policymakers (Chou, 1991; Han and Kamber, 2001). Since 2018, this approach has been successfully employed in urban and regional studies (see, e.g. Bocci et al., 2024, Borsekova et al., 2018, 2024, 2025; Borsekova and Korony, 2023). Importantly, decision trees can capture non-linear interactions thereby aligning with our expectation of conditional dynamics. They also address multicollinearity by selecting the most informative among correlated predictors, a particularly valuable feature given the interdependence of many institutional and innovation indicators.

Another contribution of our methodological approach lies in the visualisation of decision trees, which enables the precise spatial

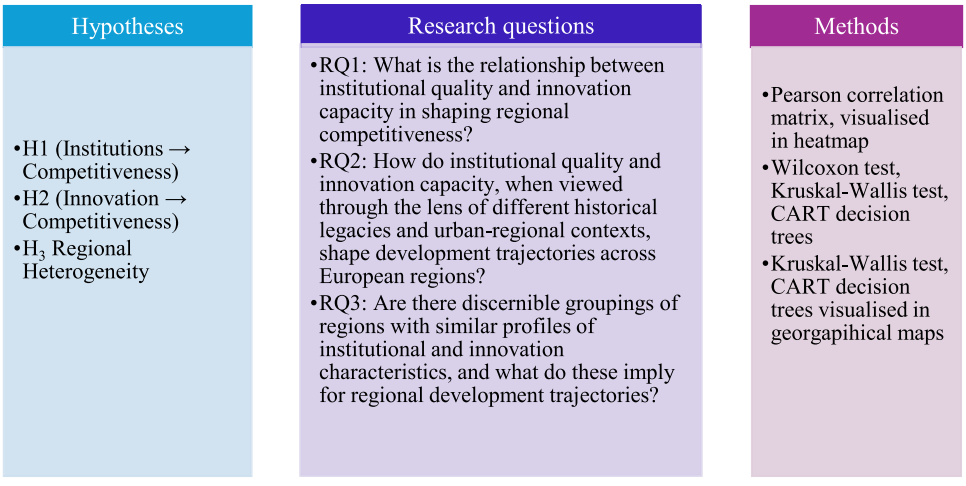

Fig. 1. Empirical strategy.

representation of regional differentiation. This facilitates a more granular understanding of how regions cluster into distinct archetypes, highlighting the thresholds that separate successful from lagging areas.

Our empirical strategy combines exploratory techniques (correlations and clustering), non-parametric tests, and CART modelling to build a robust analytical framework. This allows us not only to examine the relationships between institutions, innovation, and competitiveness, but also to construct a taxonomy of European regions. In doing so, we uncover development patterns of regions across the EU, thresholds in key indicators that redirect trajectories, and the extent to which institutional and innovation drivers overlap or diverge in explaining regional outcomes.

All statistical reports, graphics, and maps were produced using statistical software: IBM SPSS Statistics (version 25) and NCSS (version 2024).

4. Results

4.1. Relationship between institutional and innovation indicators

We first examine how institutional quality correlates with innovation-related indicators across the 233 regions. Fig. 2 (heatmap of the correlation matrix) and Annex 1 (selected correlation coefficients) summarise these relationships.

Several patterns emerge. First, there is a positive correlation between institutional quality and innovation capacity. Regions scoring higher on institutional indicators (*Control of Corruption*, *Quality of Government*, *Impartiality*) also score higher on innovation. *Control of Corruption* correlates at $r \approx 0.50$ with patents, $r \approx 0.55$ with *R&D expenditure* (both $p < 0.001$). *Quality of Government* correlates strongly with *knowledge workers* and *HRST*. These support H_1: better governed regions foster

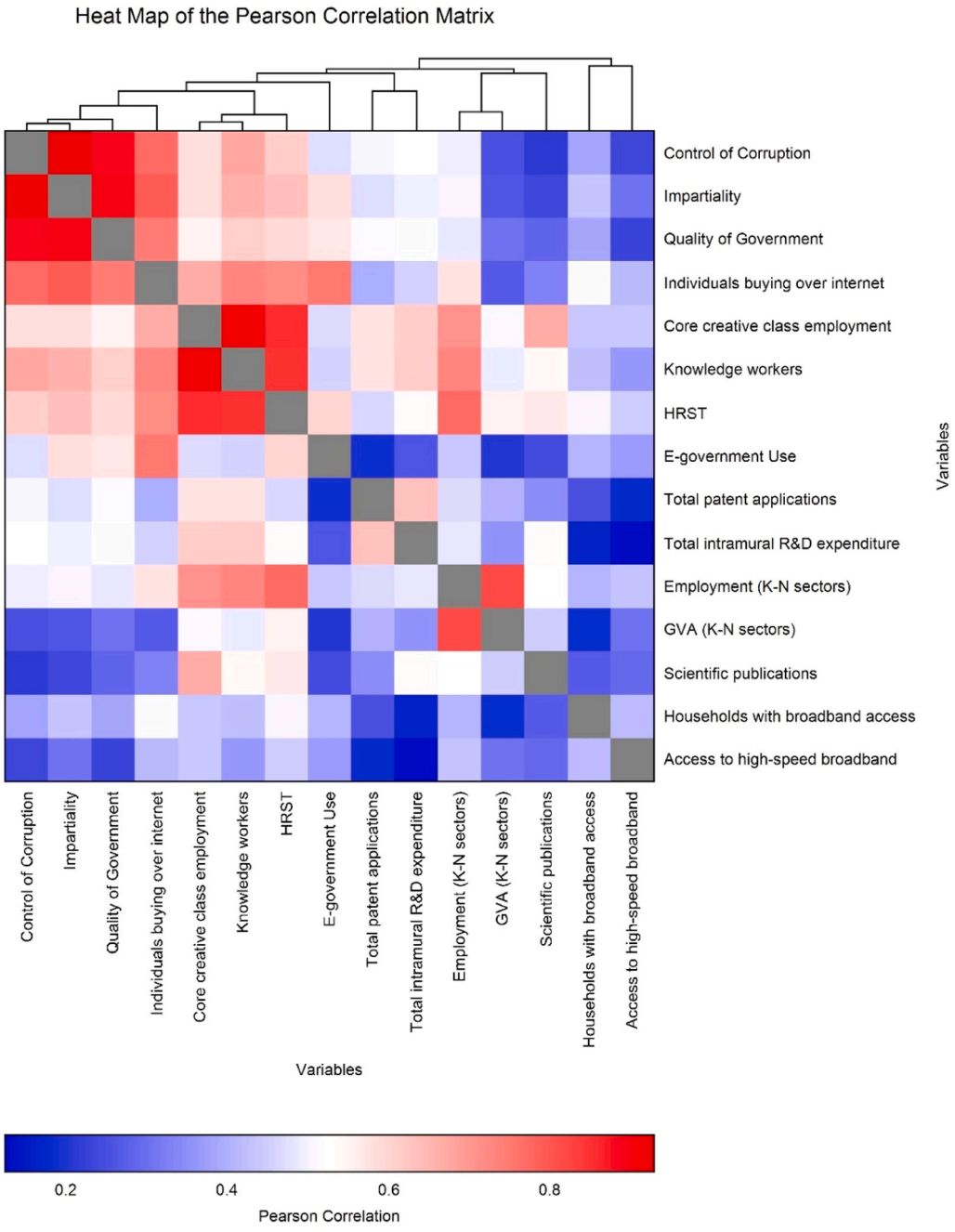

Fig. 2. Heatmap of indicators with a hierarchical clustering dendrogram.

stronger innovation ecosystems, aligning with prior findings (e.g., Rodríguez-Pose and Di Cataldo, 2015). Notably, *Quality of Government* shows the strongest, most consistent correlations with innovation variables, suggesting general public service quality underpins innovation potential.

Second, innovation indicators cluster. Many variables move together. High patent regions have high R&D spending ($r \approx 0.7$) and large knowledge worker proportions ($r \approx 0.6$). *Core creative class employment*, *knowledge workers*, and *HRST* form one cluster, reflecting a talent base. *Patents* and *R&D* pair (output with input), with *scientific publications* tying in. Regions strong in formal R&D normally also excel in patents and academic output. These clusters (Fig. 2) illustrate innovation as multifaceted, though broad correlations suggest an underlying "regional innovation capacity."

Third, institutional indicators correlate with each other, as do innovation sub-dimensions. Particularly, there is a high correlation exists *Control of Corruption* and *Impartiality* (less corrupt administrations are more impartial; $r > 0.8$), and between these and *Quality of Government* ($r \approx 0.9$, by construction the QoG index encompasses the other two). *E-government use* correlates moderately with survey-based indices ($r \approx 0.4$–0.5): stronger institutions correlate with greater digital service uptake. On innovation, *Broadband access* has a weak correlation with many outcomes (generally $r < 0.2$, often not significant). By the late 2010s, basic broadband coverage was high in most regions (median 90 per cent), no longer distinguishing innovation.

To dig deeper into RQ2, we perform group comparisons. We divide regions into Western vs CEE and compare their indicator values. Table 3 reports the median values of each indicator for the two groups, along with Wilcoxon rank-sum test results for differences. The results reveal a stark contrast across nearly all indicators.

Institutional quality is significantly higher in Western regions (Table 3). Median *Quality of Government* amongst Western regions is 0.50 versus −1.06 in CEE (*p* < 0.001). Median *Control of Corruption* is also much higher in the developed group. These gaps confirm governance standards are substantially lower in CEE regions. Many CEE regions have negative QoG z-scores (below-EU-average governance), whereas most developed regions have positive scores (Table 3).

Innovation metrics show similar dramatic disparities. Patent activity is clearest: median applications per million are 64.8 in Western regions versus 5.8 in CEE; a more than tenfold difference. This highlights much stronger innovation ecosystems in high-income regions, where robust R&D and industry presence drive patenting, compared to low-income regions lacking infrastructure or having recently initiated innovation efforts. Other indicators follow: R&D expenditure medians are 1.6 per cent of GDP for developed regions versus 0.8 per cent for CEE; knowledge workers comprise 29.5 per cent of workforce in developed regions versus 23.5 per cent in CEE; creative-class employment is likewise higher (10.6 per cent versus 8.4 per cent). All differences are statistically significant ($p < 0.001$). These support H_2: regions lagging economically also lag in innovation capacity

Technological readiness indicators show online shopping and high-speed broadband favouring Western regions, reflecting more advanced digital adoption. Conversely, broadband access is nearly universal (around 90 per cent in both groups), no longer differentiating between regions in Europe. CEE regions caught up in basic infrastructure but lag in digital use intensity and next-generation access, showcasing that simple infrastructure converges more easily than complex innovation capacities.

Business sophistication differs, though less starkly. Western regions report higher median GVA in knowledge-intensive sectors (23.7 per cent versus 16.5 per cent) and employment in those sectors (14.5 per cent versus 8.6 per cent). These activities remain concentrated in wealthier regions, especially major cities (Île-de-France, Stockholm, Munich). By contrast, rural and peripheral CEE regions have smaller knowledge service bases.

Wilcoxon tests confirm institutional and innovation divides mirror economic divides, with parity observed only in basic connectivity. These reinforce H_3: CEE regions, particularly non-capitals, systematically underperform compared to Western and Northern counterparts. Kruskal–Wallis comparison of four groups (Western capitals, Western others, CEE capitals, CEE others) shows significant differences for most indicators ($p < 0.001$). Within CEE, capitals (Prague, Warsaw, Budapest) clearly outperform other regions, with better governance scores and stronger innovation outcomes (patents 12 versus 3 per million), reflecting their role as political, economic, and knowledge hubs (Table 4)

Western capital regions score highest (Stockholm, Paris, Berlin rank top). However, the gap between Western capitals and non-capitals is smaller than in CEE. In high-income countries, non-capital regions (Bavaria, Rhône-Alpes) often have strong institutions and innovation too. In highly competitive economies, benefits spread more evenly or multiple growth poles exist. Germany, for instance, lacks an overly dominant economic hub.

National capitals, regardless of development level, rank at or above other regions in their group. Hence, development level and capital status both significantly influence performance. Western regions outperform CEE ones across the board; within each category, capitals often outperform others. These offer nuanced backdrop for decision-tree analysis: simple binary splits (East versus West) capture much variance, but certain regions, notably capitals, defy broader trends. Decision trees reveal if and how such nuances manifest when algorithms optimally split data.

Table 3
Comparison of institutional and innovation related indicators between CEE regions and Western regions.

Indicator / Phase	CEE		Western		Wilcoxon test
	Mean	Median	Mean	Median	p value
Control of Corruption	-0.90	-0.81	0.29	0.56	0.000
Quality of Government	-1.06	-1.06	0.35	0.50	0.000
Impartiality	-0.89	-0.94	0.28	0.56	0.000
E-government Use	55.52	57.00	69.24	71.00	0.000
Households with broadband access	89.13	90.00	89.41	90.00	0.646
Individuals buying over internet	58.64	61.00	68.16	73.00	0.000
Access to high-speed broadband	28.75	27.19	39.70	34.57	0.044
Employment (K-N sectors)	9.70	8.57	15.23	14.51	0.000
GVA (K-N sectors)	17.96	16.54	24.30	23.68	0.000
Total patent applications	10.38	5.77	128.21	64.83	0.000
Core creative class employment	9.29	8.39	11.04	10.65	0.000
Knowledge workers	24.84	23.54	28.13	29.44	0.003
Scientific publications	0.95	0.72	1.23	1.13	0.004
Total intramural R&D expenditure	0.98	0.80	1.85	1.59	0.000
HRST	40.02	38.40	46.25	47.30	0.000

Note: if p = 0.000 it means p < 0.001

4.2. Comparative analysis via decision tree modelling

Decision tree modelling provides a powerful framework for analysing indicator interplay and how they collectively distinguish development outcomes. We present two complementary analyses: one using institutional indicators (4.2.1), one using innovation indicators (4.2.2). In each, the target variable is development level. Finally, we present the tree jointly incorporating all indicators. The goal: see which combinations best allocate regions into developed or less developed categories, highlighting critical factors and thresholds. Together, these explain H_1–H_3 by revealing decision rules approximating conditional relationships between institutions, innovation, and development.

Table 4
Test of medians of indicators among four groups of regions.

Indicator / Group	CEE - Other	More developed - Other	CEE - Capital	More developed - Capital	p
Control of Corruption	-0.82_a	0.57_b	-0.78_a	0.33_b	0.000
Quality of Government	-1.00_a	0.54_b	-1.23_a	0.17_b	0.000
Impartiality	-0.96_a	0.57_b	-0.72_a	0.30_b	0.000
E-government Use	56.50_a	70.00_b	78.00_b	79.49_b	0.000
Households with broadband access	90.00_a	90.00_a	90.00_{ab}	93.00_b	0.010
Individuals buying over internet	61.00_a	72.00_b	69.00_{ab}	78.33_b	0.000
Access to high-speed broadband	26.71_a	33.86_b	63.19_b	56.21_b	0.048
Employment (K-N sectors)	7.91_a	14.01_b	17.30_c	22.09_d	0.000
GVA (K-N sectors)	15.36_a	23.30_b	27.86_c	31.46_d	0.000
Total patent applications	5.40_a	61.56_c	22.35_b	156.22_d	0.000
Core creative class employment	7.98_a	10.45_b	16.25_c	15.13_c	0.000
Knowledge workers	21.91_a	28.56_b	37.50_c	36.66_c	0.000
Scientific publications	0.58_a	1.00_b	1.92_c	2.11_c	0.000
Total intramural R&D expenditure	0.66_a	1.55_b	1.45_b	1.92_b	0.000
HRST	36.50_a	46.60_b	54.20_c	59.81_c	0.000

Note. Medians with different subscripts differ at the p = 0.05 level by stepwise multiple comparison test, p – p value of Kruskal-Wallis test.

4.2.1. *Decision tree model with institutional indicators as inputs*

We include four institutional indicators (*Control of Corruption*, *Quality of Government*, *Impartiality*, *E-government use*) as independent variables, attempting to predict whether a region is Western or CEE. This addresses: How well can we classify development status using only governance measures? Which aspects matter most for distinguishing high versus low performers?

The resulting CART tree (Fig. 3) displays a simple yet informative structure despite using only four inputs, partitioning 233 regions into segments defined by institutional quality thresholds. The root node split is on *Quality of Government* (QoG). Regions with QoG above this threshold go right (mostly Western), those at or below go left (tending CEE). This first split creates major division: most Western and Northern regions (positive QoG scores) are separated from most CEE and some Southern regions (negative scores). QoG prominence at the root underscores its importance as the single most informative institutional predictor. Regions with even moderately good quality of government are far more likely economically advanced.

In the lower-quality group, *Control of Corruption* emerges as next most important discriminator, subdividing regions by impartiality degree. Within the high-quality branch, QoG drives subsequent splits, refining distinction amongst well-governed regions. Overall QoG appears in multiple splits (at root and again at lower level), highlighting its central role. *Impartiality* and *Control of Corruption* each appear twice. *E-government use* appears once. QoG's repeated presence indicates strong gradient effect; not just one-time threshold, but finer gradations continue distinguishing regions.

The tree produces several terminal nodes (leaves), each representing regions with similar institutional profiles. More developed regions generally have QoG scores near or above zero, often with at least moderately good scores in *Control of Corruption* and *Impartiality*. Many Western European regions fall into these leaves. Notably, a few CEE regions achieving relatively good governance (Estonia, Slovenia, scoring around EU average on QoG, having tackled *Control of Corruption* comparatively well) also classify correctly as "Western," showing the model captures actual institutional conditions, not merely an "East-West" dummy.

CEE group regions typically show low QoG and either low Control of Corruption or low impartiality (or both). This includes most regions from Bulgaria, Romania, parts of Italy's Mezzogiorno, Greece. Outliers like Prague (QoG > 0, decent impartiality) are not in the same leaf as other Czech regions with lower scores, indicating Prague's better governance put it on a different branch, consistent with its stronger economy.

Table 5 reports median values of regions in terminal nodes. Overall medians appear in the rightmost column (Total). Comparing node-specific medians with overall parameters positions regions within the space defined by four indicators. Node 6 regions exhibit relatively high values on first three indicators, placing them amongst best performers. Node 11 regions show negative values on first three indicators, falling well below overall median on the fourth, identifying them as weakest group.

Fig. 4 maps decision-tree outcomes. The map reveals how institutional quality variations drive regional cluster formation, with Western regions exhibiting uniformly higher scores, CEE regions displaying greater variability.

Despite its simplicity, the institutional tree achieves solid classification accuracy. Table 6 presents classification matrix and performance metrics. Overall correct classification rate is approximately 91 per cent. Using institutional quality alone, we correctly predict a region's development group about 9 of 10 times. Western regions are correctly classified in 82 per cent of cases; CEE regions in all cases.

This asymmetry suggests the model particularly identifies truly struggling regions (clear signature of poor governance across multiple indicators), whereas a handful of Western regions with somewhat weaker institutions confuse the model. The examination of misclassifications shows a few borderline cases, for example southern Italian or Spanish regions economically above median but with middling QoG, were grouped with CEE regions due to institutional profiles. These reflect real-world nuances: some regions economically outperform what institutional quality alone would predict (often due to compensating factors like capital city effects or EU investments), and vice versa.

This institutional tree thus confirms H_1 with nuance: high institutional quality is near-requirement for being top-performing European region, and severe deficits almost guarantee lagging group placement. It provides specific threshold insights: having QoG index around EU average (0) seems a tipping point. Below that, regions struggle; above, they prosper. Likewise, *Control of Corruption* must be above a certain level (roughly, index above EU average of 0) to break into higher development league. *Impartiality* to ensure top-tier status also needs to be quite high, suggesting very best performers distinguish themselves by very fair, impartial governance.

4.2.2. *Decision tree model with innovation indicators as inputs*

We now turn to the tree using innovation-related indicators to predict development level. We include 11 innovation, technological readiness, and business sophistication indicators as predictors, again dividing regions between West and CEE. This addresses how well innovation measures alone distinguish leading regions from laggards, and which factors are most relevant. Because we have more predictors, one might expect even higher accuracy.

The resulting innovation tree (Fig. 5) is deeper, somewhat more complex, reflecting the larger candidate variable pool.

The root node split is on *Total patent applications per capita*. A threshold of more or less than 33 patents per million inhabitants is chosen as first cut. Regions above this intensity go right (mostly

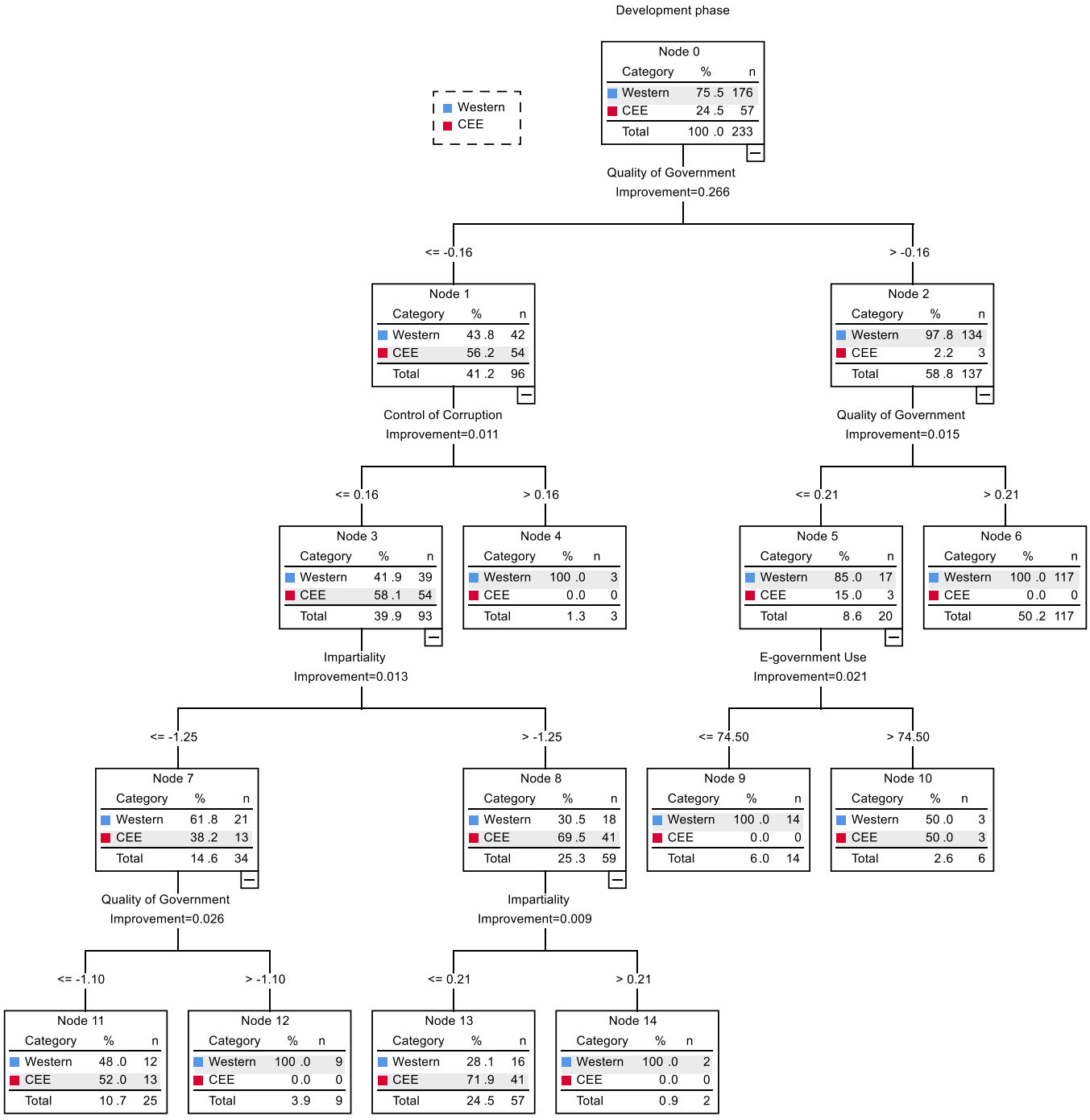

Fig. 3. CART decision tree of institutions indicators versus development phase variable. Each node shows the splitting criterion (indicator and threshold), and each terminal node is labelled with the predominant class (Western or CEE) and the number of regions in that node. For brevity, we refer to "high QoG" or "low Control of Corruption" in the text as shorthand for specific threshold conditions.

Table 5
Medians of institutions indicators by CART decision tree terminal nodes.

Indicator / Node	4	6	9	10	11	12	13	14	Total
Control of Corruption	0.34	0.86	-0.31	0.13	-1.40	-1.37	-0.72	-0.08	0.00
QoG	-0.25	0.78	-0.07	0.14	-1.47	-0.61	-0.74	-0.18	0.24
Impartiality	0.20	0.82	0.11	0.21	-1.52	-1.39	-0.84	0.29	0.24
E-government Use	71.00	76.00	67.50	81.49	36.00	66.00	60.00	78.50	67.00

Western), those below go left (mostly CEE). This confirms that patent output —a proxy for innovative output of firms and institutions— is the single most discriminating innovation metric for development. It separates large numbers of CEE and some Southern regions (typically <10

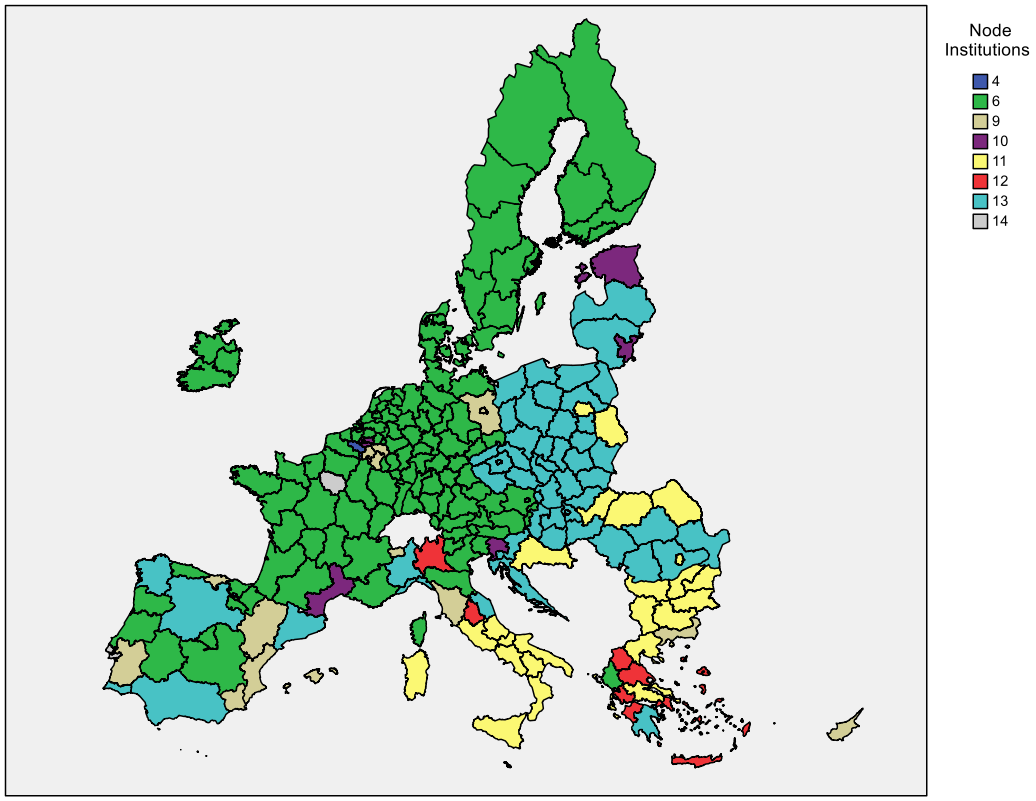

Fig. 4. Map of EU27 NUTS2 regions coloured by terminal nodes of CART decision tree institutions indicators.

Table 6
Classification table of CART decision tree of institutions indicators versus development phase variable.

Observed	Predicted by CART		
	Western	CEE	% correct predicted
Western (176 regions)	145	31	82.4 %
CEE (57 regions)	0	57	100 %
	145	88	233 (91.2 %)

patents per million) from Western-European core (many with dozens per million). Patents thus proxy overall innovation ecosystem strength.

On the high-patent branch (right), next splits involve *Knowledge workers* and *Scientific publications*. Amongst high-patent regions, the tree distinguishes those with very high human capital (top-tier innovative regions) versus those with slightly less knowledge workforce but still significant innovation (perhaps more industrial innovation rather than purely knowledge-services driven).

On the low-patent branch (left of root), the tree first splits on GVA in K–N sectors. This identifies a subset that, despite low patent output, have relatively sizeable knowledge-intensive service economies. This subset includes intermediate cases like Southern European regions where innovation output (patents) is low but the economy has service orientation (tourism, administrative centres).

R&D expenditure does not appear as top split, nor does core creative class employment explicitly. This may be because patents and knowledge workers effectively capture variance R&D or creative class would. Patents likely outcompeted R&D as predictor since they are highly correlated and patents have slightly stronger direct association with the target. Knowledge workers probably cover what creative class would have. This illustrates how decision trees handle multicollinearity: selecting one of correlated features for splits, not using others unless they add new information.

Table 7 reports median innovation indicator values across terminal nodes. The results highlight substantial heterogeneity: Node 2 stands out with very high patent applications (116.22 per million) and strong knowledge worker shares (32.25 per cent), whereas Nodes 9 and 15 record extremely low patent activity. Nodes 14 and 13 show above-average knowledge workers and GVA in K–N sectors, contrasting with weaker nodes like 5 and 10. The table illustrates how the tree separates regions into distinct groups, with clear divides between high-performing innovation hubs and structurally weaker regions.

Fig. 6 portrays geographical distribution as allocated by the model, visually representing how innovation indicators define development phases. This map highlights distinct groupings, demonstrating spatial clustering of mostly high-performing Western regions contrasting with lagging CEE regions.

This innovation-based model achieves even higher accuracy than the institutional model. Overall correct classification rate is about 95–96 per cent. The classification matrix in Table 8 shows it correctly classifies nearly all Western regions (approximately 98 per cent) and a very high fraction of CEE regions (around 95 per cent). Only a handful are misclassified. Model accuracy underscores how tightly linked innovation metrics are with economic development in EU context. The high accuracy hints the tree almost recreates development classification from inputs; innovation indicators collectively encapsulate the development divide extremely well.

The near-perfect separation achieved by innovation indicators corroborates H_2: innovation capacity powerfully discriminates regional economic performance. Regions excelling in patents, R&D, and knowledge employment are almost invariably economically leading; those lagging on these fronts are almost all economically lagging. The tree adds detail: patent output is the strongest single indicator of a region's development status amongst innovation measures. This implies the ability to translate knowledge into marketable innovations (patents as proxy) hallmarks developed regions. High shares of knowledge workers and strong engagement in knowledge-intensive services also emerge as crucial supporting factors.

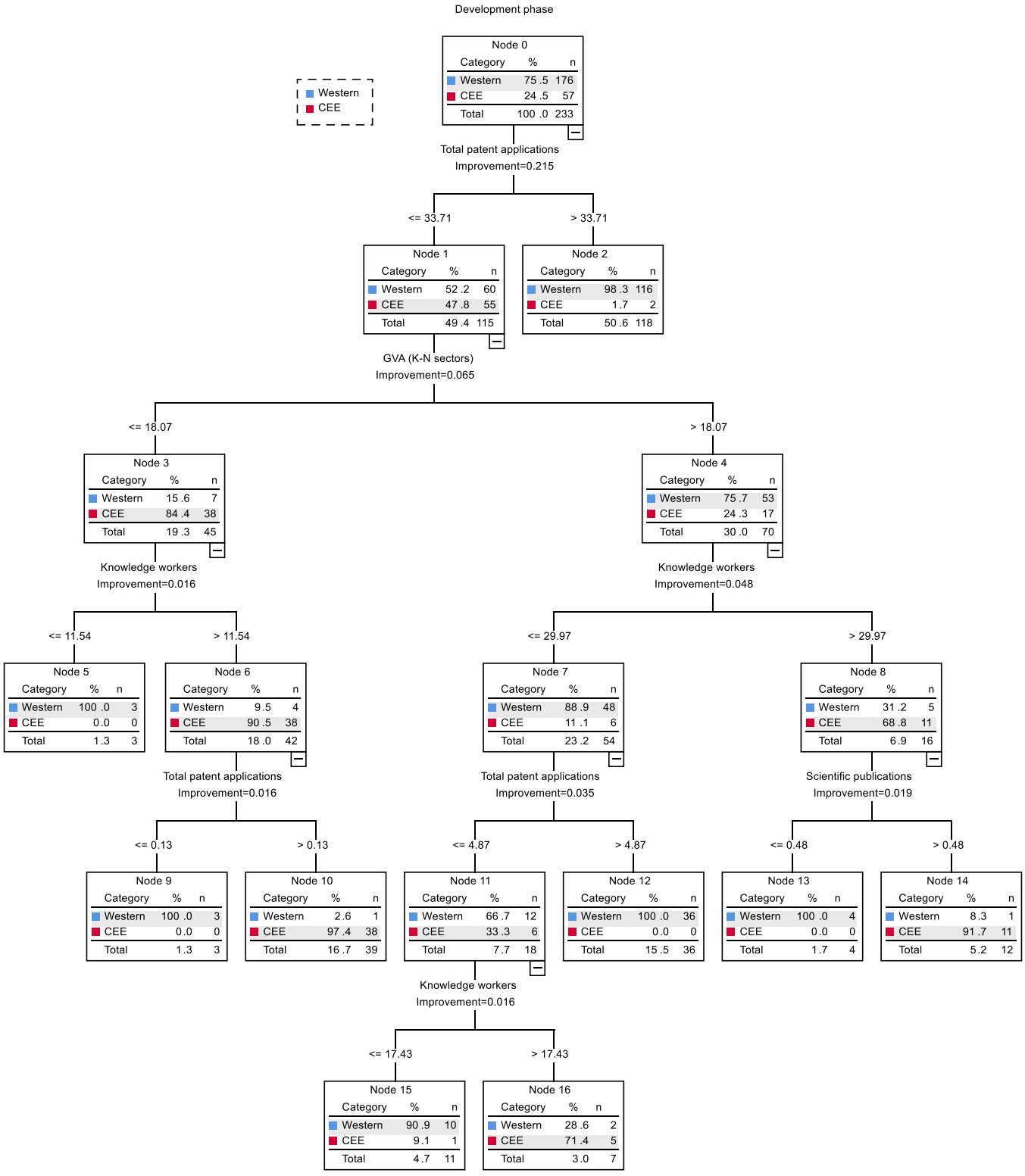

Fig. 5. CART decision tree using innovation indicators to classify regions by development level.

Comparing institutional and innovation trees yields interesting perspectives. The innovation model achieves higher accuracy, which could mean current innovation indicator levels track regional GDP per capita more closely than institutional indicators do. This might be because some institutional improvements take longer translating into GDP, or because a few regions have decent institutions but have not yet built innovation capacity (or vice versa). It also aligns with the idea that in today's advanced economies, innovation is often the proximate growth driver, though underlying institutions enable that innovation.

Finally, we present the tree jointly incorporating all institutional and innovation indicators. The model was grown using CART, with development phase as dependent variable and 15 predictors capturing institutions and innovation dimensions as independent variables. The analysis reveals clear hierarchy of indicators differentiating European

Table 7
Medians of innovation indicators by CART decision tree terminal nodes.

Indicator / Node	2	5	9	10	12	13	14	15	16	Total
GVA (K-N sectors)	24.51	17.46	15.35	15.25	23.14	21.57	27.94	19.76	22.23	22.71
Patent applications	116.22	4.44	0.00	5.49	15.74	27.27	22.16	1.48	2.42	35.34
Knowledge workers	32.25	10.87	13.36	21.91	19.89	34.23	36.03	15.96	21.88	27.31
Scientific publicat.	1.30	0.45	0.14	0.54	1.06	0.08	1.80	0.45	0.88	0.97

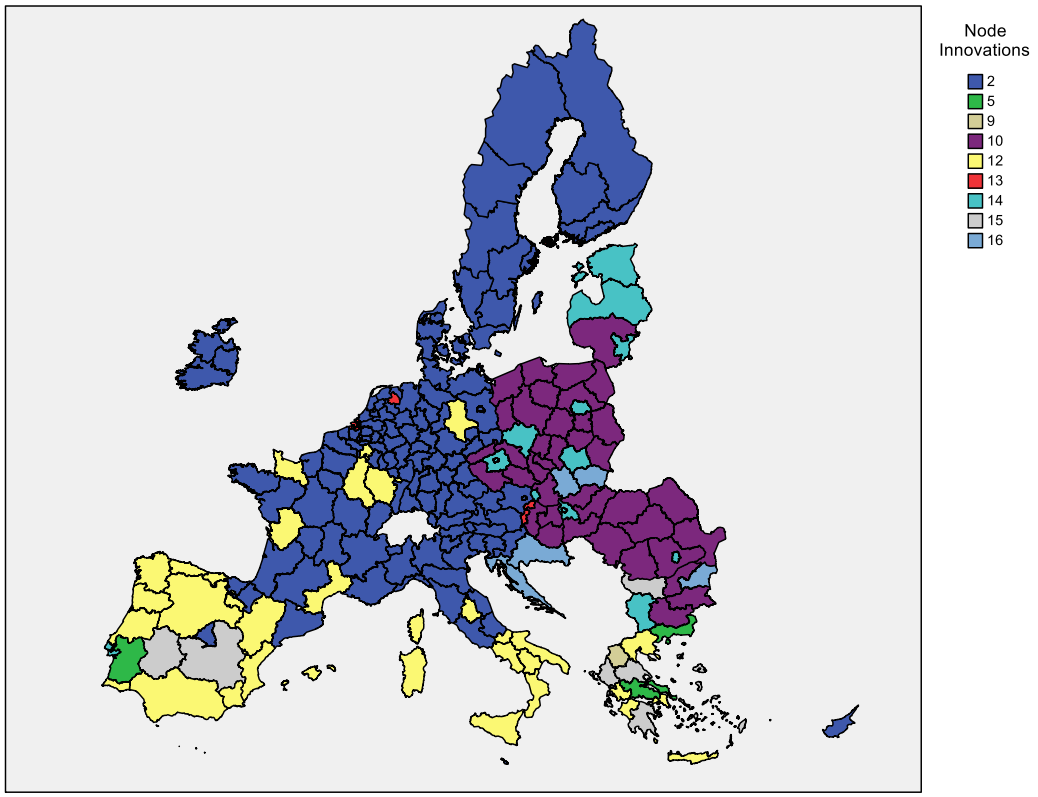

Fig. 6. Map of EU27 NUTS2 regions coloured by terminal nodes of CART decision tree innovations indicators.

Table 8
Classification table of CART decision tree of innovations indicators versus development phase variable.

Observed	Predicted by CART		
	Western	CEE	Percent correct predicted
Western (176 region)	172	4	97.7 %
CEE (57 regions)	3	54	94.7 %
	175	58	233 (96.2 %)

regions into Western and CEE phases. The resulting model contains 23 nodes (12 terminal) with maximum depth 5, achieving perfect 100 per cent classification accuracy for both groups, underscoring split robustness (Table 9).

At the root node, QoG emerges as primary discriminator, confirming institutional performance's crucial role in shaping development outcomes. Notably, QoG appears three times as predictor within the tree, highlighting its consistent, dominant influence across classification branches. The second-level split is driven by *Employment in K–N sectors*, capturing regional economy structural composition. Subsequent nodes emphasise *Total Patent Applications* and *Knowledge Workers roles*, underscoring innovation intensity and human capital contribution. At deeper levels, additional refinements come from variables like *Impartiality*, *Total Intramural R&D Expenditure*, *Core Creative Class Employment*, *Households with Broadband Access*, and *Access to High-Speed Broadband*, which sharpen classification but carry relatively lower importance compared to top-tier predictors.

Table 9
Classification table of CART decision tree of institutions and innovations indicators versus development phase variable.

Observed	Predicted by CART		
	Western	CEE	Percent correct predicted
Western (176 regions)	176	0	100 %
CEE (57 regions)	0	57	100 %
	176	57	233 (100 %)

Fig. 8 presents the relative importance of institutional and innovation indicators in classifying European regions by development phase using the CRT method.

The QoG index stands out as the most influential predictor, followed closely by *Employment in K–N sectors* and *GVA in K–N sectors*, which reflect structural economic capacities. Other significant contributors include *Total Patent Applications*, *Control of Corruption*, and *Impartiality*, highlighting the joint role of governance quality and innovation intensity. Lower-ranked but still relevant indicators, such as *Knowledge Workers*, *R&D Expenditure*, *Broadband Access*, and *Scientific Publications*, provide additional refinements to the classification. Overall, the results emphasise that robust institutional quality, supported by sectoral and innovation-related strengths, is most critical in differentiating regional

development trajectories.

The decision-tree results tell a coherent story. Strong institutions are a *sine qua non* for development (no region with very weak institutions is highly developed). Strong innovation performance distinguishes virtually all highly developed Western regions (few if any achieve high GDP without strong innovation). The interplay is evident: many innovation tree splits implicitly require base-level institutional support (patents and high knowledge employment generally arise in places with decent education and governance). Conversely, the institutional tree's classification of regions like Estonia or Slovenia as more-developed also reflects these countries' ability to foster innovation given their governance.

5. Discussion: institutions, innovation and regional development

Integrating institutional and innovation decision-tree analyses provides important insights into the interplay between governance and innovation in shaping regional development. While the broad conclusions of our research reinforce established theories that both institutional quality and innovation capacity are vital (e.g., Rodríguez-Pose, 2013; Capello and Lenzi, 2013), our analysis offers more granular understanding of how these factors converge across specific regional groups.

Regarding H_1 on institutions' role, our evidence strongly supports that institutional quality matters greatly. No region with poor institutions achieved high performance in our sample; conversely, all top performers had at least moderately good institutions. This implies governments aiming to improve outcomes cannot ignore governance reforms. It validates the argument that "institutions matter" at regional level (Rodríguez-Pose, 2013). Results hint accountability and government quality may be even more influential than solely controlling corruption. Additionally, the decision tree including all indicators (Fig. 7) shows QoG is the primary discriminator, appearing three times as predictor and underscoring its consistent, dominant influence. Variable

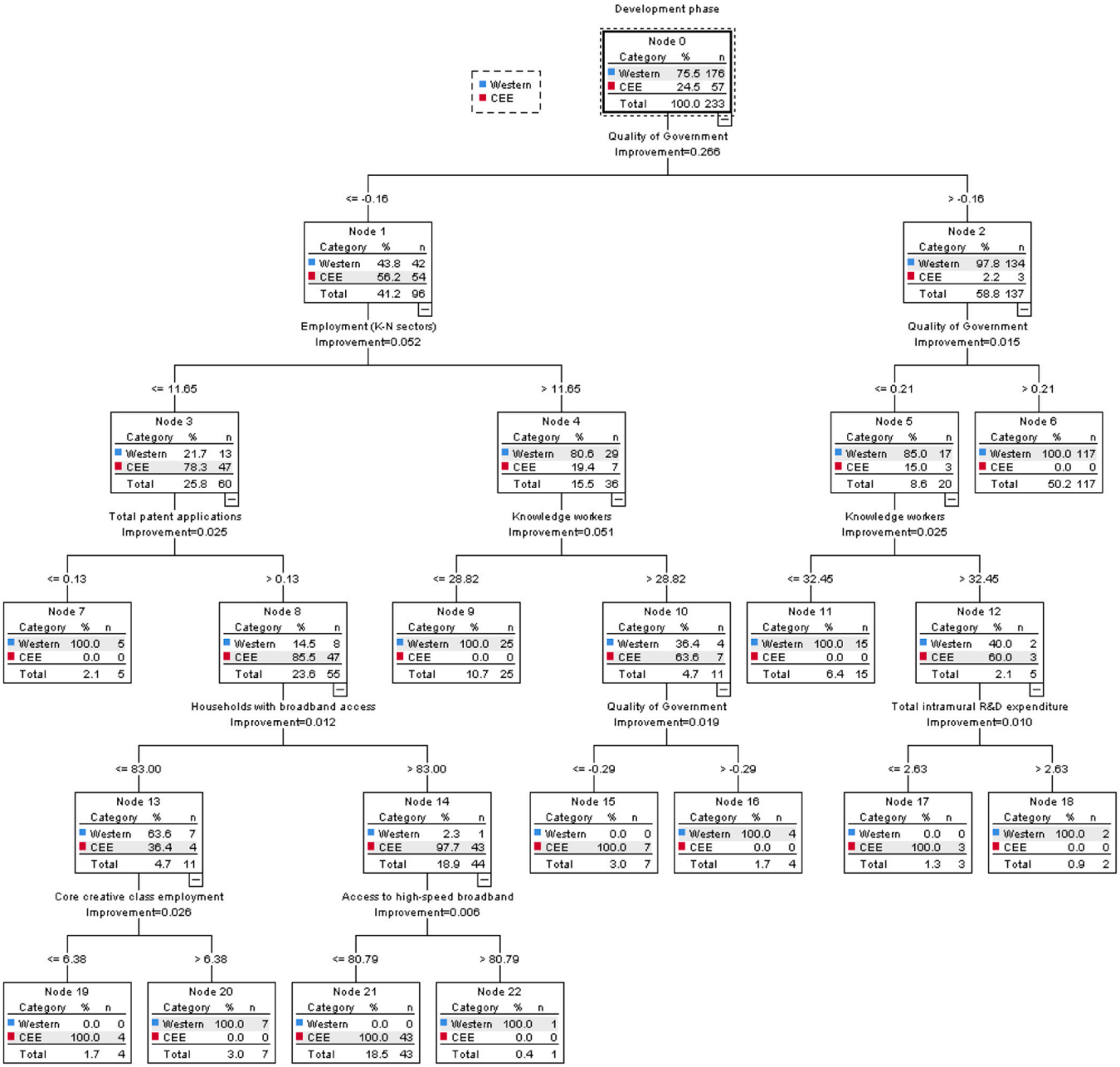

Fig. 7. CART decision tree of institutions and innovation indicators versus development phase variable.

importance analysis (Fig. 8) confirms this, with QoG emerging as most influential predictor.

Considering H_2 on innovation's role, the results also strongly confirm innovation capacity (technology, skills, knowledge creation) is a key differentiator of successful regions. The extremely high accuracy of innovation-based classification suggests that, in today's Europe, regions can be ranked by innovation indicators. Innovation is that central to competitiveness. Of course, some is endogenous (richer regions invest more in R&D), but it is also causative (innovation leads to productivity and new industries). Our findings particularly single out patents and knowledge workers as summary indicators. Regions cultivating high-skilled workforces and translating ideas into new products (patents) are leagues ahead (Asheim et al., 2011; Foray et al., 2012).

Finally, consistent with H_3, we observe discernible groupings consistent with historical contexts: a broad West/North versus East/South divide persists in both institutional and innovation terms, with West/North generally in virtuous circle of high institutions plus innovation, East/South working to escape lower equilibrium. However, our analysis also highlights gradients and exceptions: a continuum exists from weakest to strongest, with intermediate cases (many Central European regions improving). It is no longer binary East-West division; rather, a spectrum where many regions (many in Central Europe or large parts of Iberia) lie mid-way, having made progress on some fronts but not all. This nuances convergence debate. Convergence is happening, but unevenly. Some Eastern regions (especially capitals and innovative hubs like Poznań or Cluj) rapidly catch up, whilst others remain stuck. Meanwhile, a few Western regions (especially in the Mediterranean, such as parts of Greece or southern Italy) underperform relative to country peers, showing legacy of weaker institutions can hamper even within old EU members (Camagni et al., 2020).

Our main contribution lies in operationalising these theoretical insights into empirically driven classification. We have provided concrete rules defining regional archetypes: for example, "Regions with Control of Corruption index > 0.1 and > 33 patents/million are likely high-performing," essentially mapping theory into decision rules. This offers a template for policymakers to identify which regions fall into which category and why. The methodological innovation of using decision trees is itself instructive: it shows a way to communicate complex interactions straightforwardly.

Additionally, combined analysis revealed a small but important set of regions where innovation seems to compensate for weaker institutions (some Italian or Greek regions that, despite governance issues, maintain decent income possibly via strong enterprise or EU support) and conversely regions where strong institutions exist but innovation lags (some CEE capitals in early 2000s had good governance due to EU integration but low innovation; this is changing as innovation picks up). These cases illustrate dynamic scenarios: a region can partially overcome one deficit with strength in the other, but likely only to a degree. Truly sustainable development probably requires both pillars solid.

For Europe, our discussion underscores a fundamental message: institutions and innovation are not independent growth drivers but deeply interdependent. Regions managing to develop both tend to thrive; those lacking in one or both tend to struggle. This interdependence echoes "systemic competitiveness" (Esser et al., 1996) where multiple elements must align. High-quality institutions create enabling conditions for innovation by building trust, reducing uncertainty, ensuring fair competition (Rodríguez-Pose, 2013). Robust innovation ecosystems magnify returns on good institutions by driving productivity, diversification, adaptability (Boschma and Frenken, 2011).

However, we have to knowledge several limitations. The cross-sectional design does not allow us to fully rule out endogeneity: better institutions promote innovation but innovation and economic prosperity also reinforce institutional quality. Our analysis therefore highlights associations and thresholds rather than causal mechanisms. Longitudinal studies or instrumental-variable approaches would be needed to more directly address these limitations, representing a promising avenue for future research.

6. Conclusions

For decades, the EU's development strategy has championed innovation as panacea for economic divergence. Through strategies like smart specialisation, it has urged regions to explore and amplify niche technological strengths (Foray et al., 2012). Institutional reform's role was, in contrast, relegated to the margins. We argue that such an approach is not only partial but misguided. Strong institutions are not luxury to append once innovation engines are running. They are prerequisite infrastructure upon which those engines depend, as

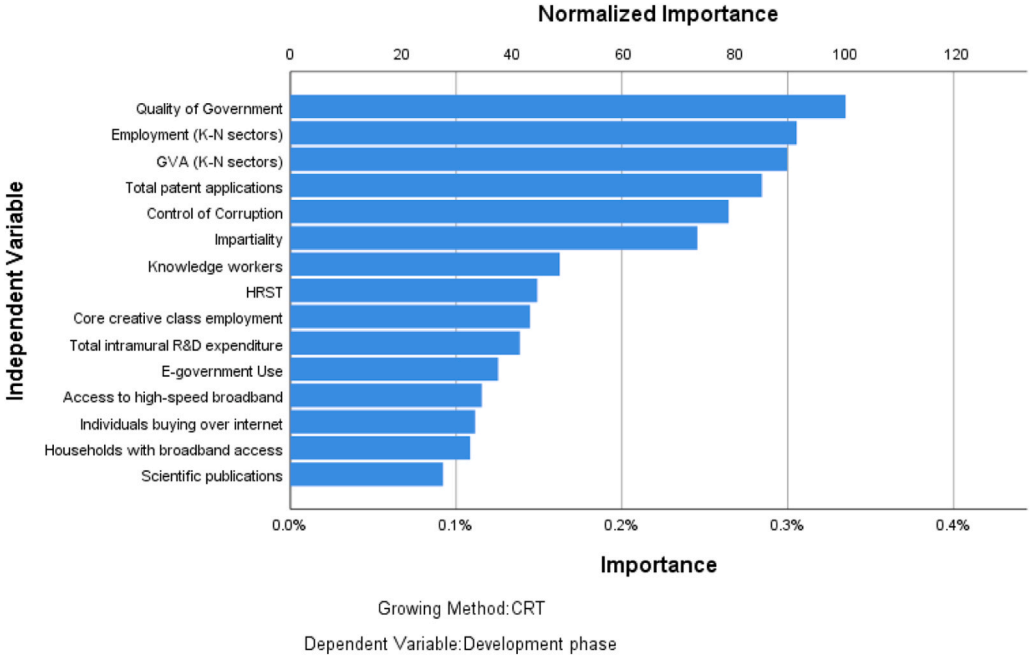

Fig. 8. Relative importance of institutional and innovation indicators in classifying European regions.

demonstrated by results on relative importance of institutional and innovation indicators, showing QoG is the most decisive factor in classifying regions into distinct developmental archetypes.

Drawing on endogenous growth theory principles (Lucas, 1988; Aghion et al., 1998) and regional competitiveness scholarship (Rodríguez-Pose and Crescenzi, 2008; Capello and Lenzi, 2013), our analysis finds innovation and institutional quality function not as parallel tracks but as interdependent systems. Innovation thrives only when embedded in an effective governance framework, while sound institutions generate returns most fully when coupled with innovation dynamism. Examined together, these forces reveal themselves as co-architects of long-term regional prosperity. It is their configuration, rather than the strength of either dimension in isolation, that determines regional developmental outcomes. This may be unsatisfactory from a pure analytical viewpoint, but from a policy perspective, this interdependence underscores the necessity to improve institutional quality and innovation potential simultaneously.

Methodologically, CART decision-tree modelling application (Breiman et al., 1984) have allowed us to embrace rather than smooth away complexity. We identified non-linear interdependencies and clustered regions based on shared institutional and innovation profiles. Our analysis indicates that if a region lacks baseline government effectiveness, then no amount of R&D investment will produce significant economic returns. These data-driven heuristics extend and refine existing understandings of institutional impact (North, 1990; Acemoglu et al., 2005) and regional innovation systems (Cooke et al., 1997; Asheim et al., 2011), offering more nuanced empirical map of regional divergence.

The analysis shows that institutional quality, particularly the repeated prominence of Quality of Government (see Figs. 3, 7 and 8), emerged as the most salient variable in determining regional success. Regions with above-average governance, found largely in Western and Northern Europe, are significantly more capable of transforming innovation inputs into economic performance. By contrast, regions suffering from institutional fragility, particularly in Central and Eastern Europe, have often failed to translate latent innovation potential into measurable outcomes. Raising the institutional quality of a low-governance region to the EU median can increase GDP per capita growth by 0.5 %age points annually (Rodríguez-Pose and Ketterer, 2020; Filip and Setzer, 2025). Institutional reform, therefore, is not merely a matter of good governance; it constitutes a strategic economic imperative.

Innovation capacity stands as indispensable counterpart. Indicators like patent intensity and knowledge worker proportion were recurrent for splitting variables in our analysis, consistently distinguishing higher-performing regions from peers. Western Europe's pre-eminence is not accidental. It is underpinned by robust human capital combined with active knowledge generation (Porter, 1998; Florida, 2002).

Critically, the relationship is not additive but multiplicative. Innovation yields its highest returns only in environments supported by effective, transparent governance. Regions at the forefront of innovation and with strong institutions, such as Stockholm and Baden-Württemberg, demonstrate how these factors reinforce one another, generating outcomes that are both economically and socially resilient. Conversely, innovation in the absence of institutional quality, or vice versa, is insufficient to sustain progress. Regions rich in talent but mired in administrative inefficiency are as hampered as well-governed regions that fail to innovate (Rodríguez-Pose and Di Cataldo, 2015). Institutional quality and innovation capacity are not substitutes; they are more than complements.

From development theory standpoint, our findings endorse the long-held view that growth is neither institutionally blind nor technologically automatic. High-quality institutions reduce uncertainty, foster trust, ensure equitable resource access (Rodríguez-Pose, 2013). Vibrant innovation ecosystems increase returns on such institutions through enhanced productivity and economic diversification (Boschma and Frenken, 2011; Schwab, 2017). Their synergy engenders a self-reinforcing cycle. Regions where the two coalesce tend not only to grow faster but also weather shocks with greater resilience (Christopherson et al., 2010). This was borne out across our regional classification: top performers consistently displayed strength in both domains, whilst weakness in either predicted underperformance.

The analysis also underscores historical legacy's enduring influence and malleability. Many CEE regions remain burdened by institutional structures ill-suited to innovation-led growth. Yet this is not irreversible. Positive trajectories in countries like Estonia and Czechia demonstrate institutional reform and strategic innovation investment can yield transformative results. Such examples defy historical disadvantage's deterministic pull and illustrate that, with targeted effort, convergence is possible (Camagni et al., 2020). Our results demonstrate that robust governance, especially high government quality, is a foundation for regional success. Innovation capacity and structural strengths act as complementary drivers. Western regions combine these advantages. Many CEE regions conversely remain constrained by governance deficits. Policy efforts should therefore target institutional strengthening alongside innovation support to close Europe's persistent regional divides.

The main policy message is that institutional reform and innovation promotion cannot be treated as distinct policy spheres. In many lagging regions, governance weaknesses such as corruption, bureaucratic inertia and ineffective administration undermine innovation efforts and stifle economic dynamism. Any drive towards competitiveness (Draghi, 2024) will underperform, or outright fail, if not accompanied by institutional strengthening. EU policy should reflect this reality, linking funding to rule-of-law compliance and investing in administrative capacity. Much remains to be done.

Equally, innovation policy must not proceed in a governance vacuum. In CEE, tailored strategies are required: more investment in higher education and R&D infrastructure, stronger ties between research institutions and local firms, improved digital capabilities. However, these must proceed hand in hand with institutional reform (Rodríguez-Pose and Ketterer, 2020). Over time, improved innovation performance may catalyse demand for better governance, inspiring a more civically engaged, skilled middle class. Smart Specialisation strategies, accordingly, must expand their purview to include institutional diagnostics and reform components (European Commission, 2014; Camagni and Capello 2013). The inverse is also true: governance reforms ought to be designed with innovation in mind, streamlining regulatory processes, enhancing transparency, facilitating entrepreneurial activity. Bridging the divide between governance "software" and innovation "hardware" will deliver more enduring results than addressing either in isolation.

Even the most advanced regions are not immune to stagnation. Sustaining development's virtuous cycle requires constant recalibration. Institutions must evolve to meet emerging challenges, be it artificial intelligence governance or transition to green economies, whilst innovation systems must continue investing in future-facing capabilities. Regional success is not permanent condition; it must be earned anew.

Regional development in the European Union hinges on the interplay between institutional robustness and innovation capacity. Through decision-tree analysis lens, we have identified specific configurations driving success, and deficiencies leading to stagnation. These insights should inform more integrated policy approaches bridging the artificial divide between economic strategy and institutional reform. Future research may build upon this work by exploring how these dynamics evolve over time or by incorporating additional dimensions such as human capital, physical and social infrastructure and social capital (Antonietti et al., 2025, Filippetti and Zinilli, 2023; Westlund, 2006). For the present, however, the policy imperative is clear: to achieve balanced and sustainable growth across Europe, good governance and innovative capacity must advance in unison. Only by treating them as inseparable pillars of development can the European Union hope to narrow its enduring regional divides.

CRediT authorship contribution statement

Kamila Borsekova: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Samuel Korony:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Andrés Rodríguez-Pose:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Michal Styk:** Writing – original draft, Formal analysis, Conceptualization. **Hans Westlund:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT-5 model in order to improve readability and language. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Kamila Borsekova reports financial support was provided by Horizon Europe research and innovation programme. Kamila Borsekova reports financial support was provided by EU NextGenerationEU, Recovery and Resilience Plan for Slovakia. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.pirs.2025.100133.

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