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An Assessment of Regional and Urban Innovation Systems in Colombia

Una evaluación de los sistemas regionales y urbanos de innovación en Colombia

Andrés Aleán-Romero
aaleanr@utb.edu.co
Instituto de Estudios en Desarrollo, Economía y Sostenibilidad-IDEEAS,
Universidad Tecnológica de Bolivar

Tania Jiménez Castilla
tjimenez@utb.edu.co
Instituto de Estudios en Desarrollo, Economía y Sostenibilidad-IDEEAS,
Universidad Tecnológica de Bolivar

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Abstract

This study examines the efficiency of Regional Innovation Systems (RIS) and Urban Innovation Systems (UIS) in Colombia using Data Envelopment Analysis (DEA) and identifies their main determinants within the framework of the Triple Helix model of innovation. We evaluate how regions and cities transform R&D investment and skilled labor into innovation outputs, including patent activity and scientific publications. The results reveal substantial heterogeneity in innovation efficiency, with a pronounced polarization between highly efficient and low-performing territories. Panel data estimations show that regions with a stronger presence of high-quality universities and higher business density achieve significantly higher efficiency levels. Institutional factors also matter: greater judicial efficiency is positively associated with innovation performance at both the regional and urban levels, while higher job satisfaction enhances innovation efficiency particularly in urban systems. These findings highlight the importance of combining academic capacity, entrepreneurial dynamics, and institutional quality to strengthen territorial innovation performance in developing economies.

Keywords: Patent activity; regional innovation systems; urban innovation systems; Data Envelopment Analysis; random effects.

Resumen

Este estudio calcula los puntajes de eficiencia para los Sistemas Regionales de Innovación (SRI) y los Sistemas Urbanos de Innovación (SUI) de Colombia utilizando el análisis envolvente de datos (DEA) e identifica los determinantes clave basados en el modelo de la Triple Hélice de la innovación. Evaluamos cómo las regiones y las ciudades usan la inversión en I+D y el trabajo calificado para producir patentes y publicaciones científicas. Los resultados revelan una heterogeneidad significativa en la eficiencia, con puntajes concentrados en ambos extremos. Los modelos de datos de panel indican que los territorios con una mayor oferta de universidades de alta calidad y una actividad empresarial más densa tienen mejor desempeño. Un proceso legal más ágil mejora la innovación, tanto a nivel urbano como regional, mientras que la satisfacción laboral mejora la innovación urbana, fomentando un entorno más dinámico para la innovación.

Palabras clave: Actividad de patentes; sistemas regionales de innovación; sistemas urbanos de innovación; análisis envolvente de datos; efectos aleatorios.

JEL Classification / Clasificación JEL: O30.

1. Introduction

Since the seminal contribution of Romer (1990), there has been broad consensus in the economics profession that innovation—driven by the intentional investment decisions of utility-maximizing agents—constitutes one of the main engines of long-run economic growth. The stock of knowledge used by societies to transform raw materials, capital, and labor into goods and services expands with each scientific and technological breakthrough. As a result, fostering innovation has become a central policy objective for governments worldwide.

In the Colombian case, one of the stated goals of the 2018–2022 National Development Plan was to "become an international benchmark in sustainability, science, technology and innovation" (Departamento Nacional de Planeación, 2018). Despite this ambition, the country continues to lag in knowledge production and research and development (R&D) investment. In 2020, Colombian residents filed only 7.2 patent applications per million inhabitants, while total R&D expenditure amounted to just 0.3% of GDP (World Bank, 2022). In contrast, global innovation leaders such as South Korea, Japan, Israel, and Sweden registered 3,490.8, 1,804.3, 182.4, and 169.6 patent applications per million inhabitants, respectively, and invested between 3.3% and 5.4% of GDP in R&D. Colombia's underperformance is evident even within the Latin American context: Brazil and Argentina recorded 24.6 and 20.2 patents per million inhabitants and invested 1.3% and 0.5% of GDP in R&D, respectively. These figures underscore the need to identify policies capable of strengthening innovation performance at both the national and subnational levels.

Most empirical evaluations of Regional Innovation Systems (RIS) have focused on large middle-income or high-income economies. Of the fifteen studies reviewed by Zemtzov and Kotsemir (2019), seven analyze Chinese provinces, five examine Russian regions, and three focus on European countries. The limited attention paid to lower-income economies reflects the view that technological progress in such contexts is largely driven by imitation rather than endogenous innovation (Feng, 2012; Feng et al., 2021). By contrast, middle- and upper-middle-income economies increasingly engage in their own innovation processes. Since Colombia transitioned from lower-middle-income to upper-middle-income status in 2008 (World Bank, 2021), a systematic evaluation of its subnational innovation systems is both timely and relevant. This study contributes to filling an important gap in the literature, as evidence on the functioning of RIS in small upper-middle-income economies—particularly in Latin America—remains scarce.

Accordingly, this paper evaluates the performance of Colombia's Regional Innovation Systems (RIS) and Urban Innovation Systems (UIS) over the period 2019–2022. Identifying which regions and cities transform innovation inputs into technological outputs more efficiently—and understanding the factors behind these differences—is essential for the design of effective innovation policies. The analysis focuses on the interaction between firms, universities, institutional quality, and labor-market conditions to explain disparities in the creation of new technologies and scientific publications across territories.

This study contributes to the regional innovation systems literature by providing systematic empirical evidence on the determinants of innovation efficiency in a developing-country context. Using regional and urban data for Colombia, the paper tests five theoretically grounded hypotheses related to agglomeration forces, knowledge institutions, entrepreneurial dynamics, labor conditions, and institutional quality. The results indicate that denser business environments, broader coverage of high-quality universities, greater judicial efficiency, and higher levels of employee satisfaction are associated with superior innovation performance. By evaluating these factors within a unified empirical framework, the study shows that innovation efficiency depends on the joint interaction of structural, institutional, and human-capital dimensions rather than on isolated policy instruments. In doing so, the paper extends innovation systems theory to a middle-income economy characterized by pronounced territorial heterogeneity and provides support for integrated, place-based innovation strategies.

Based on this motivation, the study addresses the following research questions:

(i) How efficiently do Colombian regions and cities transform innovation-related inputs into technological and scientific outputs?

(ii) Which structural, institutional, and organizational factors explain the observed differences in innovation efficiency across territories?

(iii) To what extent do the interactions between universities, firms, government institutions, and labor-market conditions shape regional and urban innovation performance in a developing-country context?

The remainder of the paper is organized as follows. Section 2 presents the theoretical and empirical background, grounded in the Triple Helix model of innovation (Etzkowitz and Leydesdorff, 1995; Etzkowitz, 2008). Section 3 describes the data and methodology used to measure innovation efficiency and analyze its determinants. Section 4 discusses the empirical results. Section 5 concludes and outlines policy implications derived from the findings.

2. Theoretical and empirical background

The Triple Helix model, first proposed by Etzkowitz and Leydesdorff (1995), serves as the theoretical underpinning for the analysis in this paper. Several recent studies have provided theoretical extensions and empirical evaluations of the model (Jovanović et al., 2022; Hu et al., 2021; Kang et al., 2019; Patra and Muchie, 2018). The central proposition of the Triple Helix model is that, in a knowledge-based economy, innovation and economic growth emerge from the interaction between academia, industry, and government, thereby creating a network of different types of entrepreneurs: private, public, and academic entrepreneurs.

Private entrepreneurs develop new products and services with the aim of generating private economic returns (Werker et al., 2017; Bailetti, 2012; Landström et al., 2012). Public entrepreneurs establish the institutional framework necessary for the protection of property rights that make innovation possible (Klein et al., 2010). In other words, "[p]ublic entrepreneurship establishes rules of the game (for good or ill), and private entrepreneurship is the play of the game" (Klein et al., 2010, p. 5). The motivations of public entrepreneurs include improving services to their communities, stimulating innovation, gaining social recognition, and deriving income from their positions (Ostrom, 2005). Academic entrepreneurship represents an extension of teaching and research activities conducted by university faculty toward the creation of new technologies, either for private economic returns or for the fulfillment of public objectives (Etzkowitz, 2008; Perkmann et al., 2013).

While the Triple Helix model provides the core analytical structure for understanding innovation as the outcome of interactions between academia, industry, and government, these interactions do not operate in a vacuum. Their effectiveness depends on broader structural and organizational conditions that shape the functioning of regional innovation systems. In this study, agglomeration economies are conceptualized as a structural precondition that facilitates proximity, interaction, and knowledge spillovers among innovative actors, thereby strengthening the mechanisms emphasized by the Triple Helix model.

At the same time, innovation outcomes depend not only on institutional interactions but also on firms' internal capacity to absorb, adapt, and implement new knowledge. This dimension is captured through intrapreneurship (Pinchot, 1987), understood as innovative behavior within organizations, which acts as a complementary mechanism linking system-level knowledge generation to firm-level innovation outcomes. Accordingly, innovation efficiency is viewed as the result of the combined influence of spatial conditions, entrepreneurial interactions across institutional spheres, and organizational dynamics within firms. This conceptual framework guides the formulation of the study's hypotheses and provides the basis for the empirical strategy adopted in the subsequent sections.

2.1. Agglomeration economies

Agglomeration economies have long been recognized as a fundamental mechanism shaping innovation processes within territories (Meliciani and Savona, 2015). Densely populated urban environments facilitate frequent interactions among firms, universities, public institutions, and skilled workers, thereby enhancing knowledge spillovers and the circulation of tacit knowledge. Spatial proximity reduces coordination and transaction costs, increases opportunities for collaboration, and accelerates learning processes among innovative agents.

Within the Triple Helix framework, these effects are particularly relevant, as urban density intensifies the interactions between private, public, and academic entrepreneurs. Closer spatial proximity increases the likelihood of formal collaboration and informal exchanges, strengthening the networks through which knowledge is generated, recombined, and transformed into technological outcomes.

From an innovation systems perspective, these mechanisms affect not only the scale of innovative activity, but also the efficiency with which existing resources are transformed into technological outputs. Regions characterized by higher urban density are therefore expected to achieve greater innovation efficiency, as the same set of inputs can generate higher innovative outcomes due to more intensive interaction among entrepreneurial actors.

These mechanisms are consistent with empirical evidence for Colombia, where innovation activity and patenting are strongly concentrated in large metropolitan areas such as Bogotá, Medellín, and Cali. Studies on regional development and innovation in Colombia highlight the relevance of population density and urban scale in facilitating knowledge spillovers, inter-firm interaction, and access to specialized labor markets, reinforcing the role of agglomeration economies in shaping regional innovation performance (Malaver and Vargas, 2013).

Based on these theoretical arguments, the following hypothesis is proposed and empirically tested in this study:

H1 (Urban density). Densely populated cities are more efficient in new technology creation because of the greater opportunity for interaction among entrepreneurs (Zemtzov and Kotsemir, 2019; Roper and Jibril, 2024).

2.2. Private entrepreneurship

Private firms constitute a central pillar of regional innovation systems, as they represent the primary agents responsible for transforming knowledge into marketable products, processes, and technologies. Within the Triple Helix framework, private entrepreneurship plays a crucial role in converting scientific knowledge and institutional support into economic value through investment, experimentation, and commercialization activities (Etzkowitz, 2008).

A higher density of private enterprises reflects stronger entrepreneurial dynamics, greater competitive pressure, and increased demand for innovation within a territory. These conditions foster experimentation, stimulate knowledge recombination, and accelerate the diffusion of technological advances across firms through both market-based interactions and informal learning processes.

From an efficiency perspective, business density influences how effectively innovation-related inputs—such as human capital, research infrastructure, and institutional support—are utilized. Regions with a larger concentration of firms are better positioned to absorb, adapt, and exploit available knowledge, thereby enhancing the transformation of innovation inputs into patentable outputs.

In the Colombian context, regional disparities in entrepreneurial activity have also been identified as a key factor explaining differences in innovation outcomes across territories. Empirical analyses emphasize that regions with higher business density and formal firm creation tend to display stronger innovative dynamics, reflecting the importance of private entrepreneurship as a driver of regional innovation systems (OECD, 2014).

Based on these theoretical considerations, the following hypothesis is proposed and empirically tested in this study:

H2 (Business density). Innovation systems with a higher density of private entrepreneurs exhibit greater innovation efficiency (Zemtzov and Kotsemir, 2019; Pham et al., 2024).

2.3. Academic entrepreneurship

Universities represent a core knowledge-generating component of regional innovation systems. Within the Triple Helix framework, academic entrepreneurship refers to the role of higher education institutions in producing scientific knowledge, forming human capital, and engaging in collaborative activities with firms and public institutions. Through research, teaching, and technology transfer, universities act as fundamental sources of innovation inputs at the regional level (Etzkowitz, 2008).

However, the contribution of universities to innovation performance depends not merely on their presence, but on their quality, research capacity, and ability to interact effectively with external actors. High-quality universities are more likely to generate frontier research, attract skilled researchers and students, and establish durable linkages with industry and government, thereby strengthening regional knowledge networks.

From an efficiency perspective, stronger academic institutions enhance regional absorptive capacity and improve the effectiveness with which research-related inputs are transformed into technological outputs. As a result, innovation systems endowed with high-quality universities are expected to generate higher levels of innovation efficiency, even when operating with comparable resource endowments.

Evidence from Colombia also underscores the central role of universities in regional innovation systems. Prior studies document significant differences in research capacity, accreditation status, and technology transfer activities across higher education institutions, with high-quality universities playing a disproportionate role in patenting, knowledge diffusion, and university–industry collaboration (Malaver and Vargas, 2013). These findings support the relevance of university quality as a determinant of innovation performance in the Colombian setting.

Based on these theoretical arguments, the following hypothesis is proposed and empirically tested in this study:

H3 (University quality). Innovation systems with a larger supply of high-quality universities create new technologies more efficiently (Zemtzov and Kotsemir, 2019; Hausman, 2022).

2.4. Public entrepreneurship

Within the Triple Helix framework, public entrepreneurship refers to the role of government in shaping the institutional conditions that enable and support innovation activities. Rather than acting solely as a regulator, the state participates actively in the innovation process by creating the legal, organizational, and financial environment necessary for knowledge generation and commercialization.

In this regard, Etzkowitz (2008) identifies five core functions of an "innovation state," as opposed to a traditional state: (i) establishing legitimate authority in both public and private sectors to reduce uncertainty in interactions; (ii) providing fiscal incentives for research and development investment; (iii) creating rules and hybrid public–private entities that support economic life; (iv) using the legal system to grant special rights to innovators, such as patents, thereby providing temporary monopoly power; and (v) supplying public funding for basic research. Among these functions, the establishment of legal certainty and the protection of property rights are particularly relevant for innovation incentives, making the efficiency of the legal system a central dimension of public entrepreneurship.

A substantial body of empirical literature supports the relevance of institutional quality for innovation performance. Legal system quality is commonly proxied by indicators of Rule of Law, which capture perceptions of confidence in societal rules, especially regarding contract enforcement and property rights protection (Kaufmann et al., 2010). Tebaldi and Elmslie (2013) find that stronger Rule of Law significantly increases patent production in a panel of middle- and high-income countries. Similarly, Phuc et al. (2018), using a dynamic panel-data framework, conclude that institutional quality is a key driver of patent applications. From an efficiency perspective, Feng et al. (2021) incorporate legal quality as an input in a DEA model of patent and scientific publication production and show that overall innovation efficiency scores increase substantially when institutional quality is considered.

From an innovation systems perspective, an efficient legal framework reduces uncertainty, strengthens incentives to invest in inventive activities, and facilitates the transformation of research and entrepreneurial efforts into protected technological outputs. Consequently, stronger public entrepreneurship—reflected in more efficient legal institutions—is expected to enhance the efficiency with which innovation inputs are converted into patent outcomes.

While institutional quality has been widely studied in relation to economic growth and firm performance in Colombia, its specific role in shaping innovation efficiency has received comparatively limited empirical attention. Most national studies focus on business climate indicators without explicitly linking institutional performance to the efficiency of regional innovation systems. Consequently, the Colombian evidence regarding the role of legal institutions in innovation remains fragmented, reinforcing the relevance of examining institutional efficiency as a determinant of patent-based innovation outcomes.

Based on these theoretical and empirical arguments, the following hypothesis is proposed and empirically tested in this study:

H4 (Legal system efficiency). The efficient protection of special rights, such as those to intellectual property, incentivizes the registration of new patents (Anderlini et al., 2013).

2.5. Intrapreneurship

Intrapreneurship, or corporate entrepreneurship, refers to innovative behavior carried out by employees within existing organizations (Pinchot, 1987). While the Triple Helix framework emphasizes interactions among firms, universities, and government, the effectiveness of these interactions ultimately depends on firms' internal capacity to recognize, absorb, and implement new ideas. In this sense, intrapreneurship constitutes a complementary organizational mechanism that supports the functioning of regional innovation systems.

A central determinant of intrapreneurial behavior identified in the literature is employee job satisfaction. In a comprehensive review, Petra et al. (2019) conclude that job satisfaction is positively associated with intrapreneurship within organizations. Antoncic and Antoncic (2011) conceptualize job satisfaction through four dimensions measured using Likert-type scales: (i) general satisfaction, including working hours, working conditions, and organizational reputation; (ii) relationships with co-workers; (iii) remuneration, benefits, and organizational culture, encompassing salary, non-monetary rewards, promotion opportunities, education, job stability, and organizational climate; and (iv) employee loyalty. Extending this framework, Giannikis and Nikandrou (2013) incorporate promotion opportunities as an additional dimension and find a positive and statistically significant relationship with corporate entrepreneurship.

Empirical evidence further supports the role of employee satisfaction in facilitating innovative behavior within firms. De Clercq et al. (2010) show that managers' satisfaction with their organizational context increases the selling efforts associated with entrepreneurial initiatives. Similarly, Mustafa et al. (2016) find that psychological ownership—defined as a state in which individuals perceive a target, such as the firm, as "theirs" (Pierce et al., 2003)—positively affects job satisfaction, which in turn fosters intrapreneurial behavior among middle managers.

From an innovation efficiency perspective, higher levels of employee satisfaction contribute to a work environment that encourages creativity, experimentation, and the internal diffusion of knowledge. Innovation systems characterized by more satisfied workers are therefore expected to transform existing technological and institutional inputs into innovative outputs more effectively, enhancing overall system efficiency.

Although empirical evidence on intrapreneurship at the regional level in Colombia remains limited, labor-market studies highlight the relevance of job satisfaction, employment quality, and skills utilization for productivity and innovation-related outcomes. This supports the inclusion of employee satisfaction as a meaningful proxy for intrapreneurial conditions within Colombian innovation systems (OECD, 2019).

Based on these theoretical and empirical considerations, the following hypothesis is proposed and empirically tested in this study:

H5 (Employee satisfaction). Innovation systems with highly satisfied workers facilitate a more creative environment and exhibit higher innovation efficiency (Morais et al., 2021).

2.6. Analytical framework

Zemtzov and Kotsemir (2019) propose a two-stage analytical framework to assess regional innovation efficiency. In the first stage, Data Envelopment Analysis (DEA) is employed to evaluate the relationship between patenting outcomes and the resources available within regional innovation systems, using data for Russian regions over the period 1998–2012. In the second stage, the authors estimate a panel-data model to explain variations in efficiency scores through a set of structural dimensions, including agglomeration, innovation system embeddedness, technological development, interregional knowledge spillovers, institutional environment, interaction among innovation agents, and regional industrial specialization. This approach has subsequently been replicated in other national contexts, including Spain and Italy (Bresciani et al., 2021).

Building on this analytical framework, the present study adopts a comparable two-stage approach. In the first stage, innovation system efficiency is measured using Data Envelopment Analysis, capturing the ability of regions and cities to transform innovation-related inputs into patent outputs. In the second stage, a panel-data model is employed to explain the observed variation in efficiency scores using a set of theoretically grounded determinants derived from the regional innovation systems literature. These determinants correspond to key dimensions discussed in the previous subsections, namely agglomeration economies, the quality of knowledge-generating institutions, entrepreneurial density, labor-market conditions, and institutional quality. This structure ensures a close alignment between theory and empirics, while providing a formal mechanism to test the hypotheses proposed in the study.

3. Methodology and data

3.1. Methodology

3.1.1. First stage: Data Envelopment Analysis for the measurement of efficiency

To calculate the efficiency scores of the innovation systems, we use Data Envelopment Analysis (DEA). DEA is a non-parametric technique that allows for the empirical measurement of the efficiency of several decision-making units (DMU), which for the present study are the 33 Colombian departments (RIS, including Bogotá as a department) and their 32 capital cities (UIS). DEA provides an answer to the question of whether a DMU is efficient in the process of transforming a set of inputs into a set of outputs. To better understand what is referred to as "efficiency", let us define the concept of *efficiency dominance*. We say that a DMU dominates another in efficiency if the former produces at least the same level of all outputs as the latter, but using less of at least one of its inputs and no more of the others. A DMU is efficient if it is not dominated in efficiency by any other DMU, or by any linear combination of DMUs. For the inefficient DMUs, the set of DMUs that form the dominant linear combination is called the *reference set*, and it represents the nearest point in the efficient frontier to the inefficient DMU. Besides classifying the DMUs by their efficiencies, the DEA method allows for the computation of the minimum output levels required to classify a DMU as efficient.

Formally, DEA is a non-parametric linear programming technique that evaluates the relative efficiency of decision-making units (DMUs) by comparing their ability to transform inputs into outputs. Let $i=1,\dots,N$ index regions or cities (DMUs). Each DMU uses a vector of inputs, $x_i=(x_{i1},\dots,x_{iK})$, to produce a vector of M outputs, $y_i=(y_{i1},\dots,y_{iM})$. Following the innovation systems literature, inputs represent innovation-related resources, while outputs capture technological results, proxied by patent production.

An input-oriented approach is adopted, as the objective is to assess the extent to which innovation systems could proportionally reduce their use of resources while maintaining observed innovation outcomes. This orientation is particularly appropriate in contexts where inputs are more directly influenced by policy decisions, whereas innovation outputs are subject to longer and more uncertain processes.

Assuming variable returns to scale (VRS), the efficiency of each DMU is obtained by solving the following linear programming problem:

$$\min_{\theta_i,\, \lambda} \quad \theta_i$$

subject to the following restrictions

$$\sum_{j=1}^{N} \lambda_j\, y_{jm} \geq y_{im}, \quad m = 1, \dots, M,$$

$$\sum_{j=1}^{N} \lambda_j\, x_{jk} \leq \theta_i x_{ik}, \quad k = 1, \dots, K,$$

$$\sum_{j=1}^{N} \lambda_j = 1,$$

$$\lambda_j \geq 0, \quad j = 1, \dots, N.$$

In this formulation, $\theta_i \in [0,1]$ represents the efficiency score of DMU i, and the vector λ defines the reference technology constructed from observed best-performing units. A value of $\theta_i = 1$ indicates that the innovation system operates on the efficiency frontier, while values below one reflect proportional input inefficiencies.

The convexity constraint $\Sigma_{j=1}^{N} \lambda_j = 1$ allows for variable returns to scale, which is appropriate given the heterogeneity in size and structural characteristics of regions and cities.

The efficiency scores obtained from this first-stage analysis are subsequently used as the dependent variable in the second-stage panel-data model, which identifies the structural determinants of innovation efficiency across territories.

3.1.2. Second stage: Panel data analysis of the determinants of innovation efficiency

To test hypotheses H2 to H5, we estimated the panel data model described by equation (1).

$$\log(\mathbf{ISeff}_{it}) = \beta_0 + \beta_1 \log(\mathbf{BD}_{it}) + \beta_2 \mathbf{HC}_{it} + \beta_3 \mathbf{JE}_{it} + \beta_4 \mathbf{UR}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

where $ISeff_{it}$ is the efficiency score of territory (department or city) i in year t, BD_{it} is the business density, HC_{it} is high quality university coverage, JE_{it} is judicial efficiency, UR_{it} is the underemployment rate, μ_{it} represents the individual effect, λ_{it} represents the time effect, and ε_{it} is the idiosyncratic error. Table 1 shows definitions for each of the variables included in equation (1).

Urban density was not included as an explanatory variable in equation (1) since it is highly correlated with high-quality universities coverage and business density. High-quality universities coverage, defined as the number of students enrolled in high-quality universities as a percentage of total students enrolled in universities, is used as a proxy for the quality of universities. The High-Quality Accreditation is issued by the Colombian Ministry of Education after a process of self-evaluation and external evaluation by peers. A requirement for the accreditation is that the university has operated for at least eight consecutive years. Thus, high-quality coverage is also a proxy for what Zemtzov and Kotsemir (2019) refer to as *embeddedness*, that is, the degree to which the university is integrated with its regional environment. In 2020, only 66 (21%) of the 316 universities in Colombia have received the High-Quality Accreditation (SNIES, 2020).

Business density, defined as the number of companies per hundred thousand inhabitants, is used as a proxy for *inner interactions* (Zemtzov and Kotsemir, 2019) and entrepreneurial activity. The underemployment rate, defined as the number of underemployed workers as a percentage of total workers, is used as a proxy for an intrapreneurial unfriendly environment. A worker is considered underemployed if he wants to improve his income, work fewer or more hours, or make better use of his capabilities and formation, and is actively searching for another job. Since the Rule of Law measure is not available at the sub-national level, we decided to use an alternative measure of the legal system quality. More specifically, we use the legal system efficiency, defined as the number of solved cases in ordinary and administrative jurisdiction as a percentage of total new cases and unsolved cases per year, as an explanatory variable for the efficiency of the innovation process.

3.2. Data and variables

We use data compiled by the Private Competitiveness Council (CPC, after its initials in Spanish), a non-profit organization, for the calculation of the Cities Competitiveness Index and the Departments Competitiveness Index (CPC, 2022) during the years 2019-2022. The data includes information on institutional quality, tertiary education, business dynamics, labor market, and the innovation process inputs and outputs[1].

The temporal coverage of the analysis is determined by data availability and consistency across sources. At the departmental level, complete and comparable information for all variables is available for the period 2020–2022, while at the city level the corresponding data are available for 2019–2022. Both earlier and more recent years present significant gaps and methodological inconsistencies across indicators. Restricting the analysis to

1 The complete datasets can be downloaded from https://www.compite.com.co/indice-de-competitividad-de-ciudades/ and https://www.compite.com.co/indice-departamental-de-competitividad/.

these periods ensures the internal consistency of the dataset and the reliability of the efficiency measures and explanatory variables.

The empirical analysis is based on a panel dataset constructed at two spatial levels: departments and cities. The departmental sample includes 33 departments observed annually over the period 2020–2022, yielding a total of 99 observations. The city-level sample comprises 32 major Colombian cities observed over the period 2019–2022, resulting in 128 observations. The dataset combines information from multiple official sources covering innovation outputs, higher education, business activity, labor-market conditions, and institutional quality.

The data constitute a balanced panel in both samples, as all spatial units are observed in each year of the corresponding period. This panel structure allows the analysis to exploit both cross-sectional and temporal variation in innovation system characteristics, while controlling for unobserved heterogeneity across territories.

As in most previous studies, we used R&D expenditures and the number of R&D personnel as input variables and patent activity as an output variable (Zemtzov and Kotsemir, 2019). More specifically, as input variables we use (i) R&D expenditures as a percentage of GDP, (ii) number of researchers recognized by the Colombian Ministry of Science, Technology and Innovation (Minciencias) per million inhabitants, and (iii) number of high-quality research groups recognized by Minciencias per hundred thousand inhabitants. As output variables, we use the number of (i) patents, (ii) utility models, (iii) industrial designs, and (iv) registered trademarks per million inhabitants, and (v) number of journals indexed in the national index of academic journals (Publindex) per hundred thousand inhabitants. Thus, we focus on both patent and publishing activity.

Table 1. Variable definitions

Variable	Definition	Theoretical and empirical justification
IS efficiency	Efficiency scores calculated by DEA.	Zemtzov and Kotsemir (2019), Roper and Jibril (2024).
Business density	Business corporations in the territory per 100,000 inhabitants.	Zemtzov and Kotsemir (2019), Pham et al. (2024).
High-quality universities coverage	Percentage of students enrolled in higher education institutions accredited for high quality out of the total higher education enrollment in the territory.	Zemtzov and Kotsemir (2019), Hausman (2022).
Judicial efficiency	Sum of conciliation cases resolved (fully or partially) and arbitration awards, as a percentage of the total number of conciliation and arbitration requests by territory.	Feng et al. (2021), Anderlini et al. (2013).
Underemployment rate	Employed individuals who consider themselves underemployed in terms of income, working hours, or skills and who have taken steps to change this situation.	Giannikis and Nikandrou (2013), Morais et al. (2021).

Source: Authors' own elaboration.

Table 2 presents the descriptive statistics for the variables used in the empirical analysis, separately for departments (Panel A) and cities (Panel B). The table reports the mean, standard deviation, and minimum and maximum values for the indicators of innovation system efficiency and its main determinants. The sample comprises 33 departments observed over the period 2020–2022 and 32 cities observed over the period 2019–2022. All percentage-based variables are expressed as proportions, while the efficiency indices are bounded between 0 and 1. These descriptive statistics provide an overview of the level and dispersion of innovation-related characteristics across territorial units prior to the econometric analysis.

Table 2. Descriptive statistics

Panel A. Departments				
Variable	Mean	SD	Min	Max
RIS efficiency	0.585	0.383	0.001	1.000
High-quality universities coverage	0.268	0.230	0.000	0.742
Business density	5.886	4.568	0.980	25.159
Underemployment rate	0.093	0.038	0.011	0.160
Judicial efficiency	0.521	0.200	0.000	1.000
Panel B. Cities				
Variable	Mean	SD	Min	Max
UIS efficiency	0.648	0.387	0.001	1.000
High-quality universities coverage	0.300	0.240	0.000	0.792
Business density	9.231	4.592	1.374	26.708
Underemployment rate	0.082	0.036	0.005	0.176
Judicial efficiency	0.470	0.200	0.000	1.000

Note: Panel A includes 33 departments observed over the period 2020–2022 (99 observations). Panel B includes 32 cities observed over the period 2019–2022 (128 observations).
Source: Authors based on CPC (2022).

The descriptive statistics reveal substantial heterogeneity in innovation-related conditions across both departments and cities. Innovation efficiency exhibits wide dispersion in both samples, with values ranging from near zero to one, suggesting marked differences in the capacity of territories to transform inputs into innovative outputs. Coverage of high-quality universities also shows considerable variation, with several regions displaying very limited access to accredited institutions, while others exhibit relatively high coverage. Business density presents notable dispersion, particularly at the city level, reflecting uneven entrepreneurial concentration across urban areas. Underemployment rates vary significantly across territories, indicating differences in local labor-market conditions. Finally, judicial efficiency displays a broad range, from very low to full effectiveness, underscoring the heterogeneity in institutional quality across regions. Overall, these patterns highlight strong territorial asymmetries and support the relevance of a regional innovation systems approach that explicitly accounts for spatial diversity.

4. Results

4.1. Efficiency scores

There is a spatial cluster of high RIS efficiency at the Central region of the country, conformed by Cundinamarca, Antioquia, Caldas, Risaralda, and Quindío, and a spatial cluster of low RIS efficiency at the South-eastern region of the country, conformed by Caquetá, Guaviare, Vichada, Vaupés and Guainía (Fig. 1). The Caribbean region, at the north of the country, exhibits negative spatial correlation: high efficiency departments like Atlántico and San Andrés archipelago are neighbors of low efficiency departments like Cesar, Sucre and La Guajira. Likewise, the Pacific region, to the west of the country, has only one highly efficient department, Valle del Cauca. We obtained a small but significant positive value for Moran's I (0.07). The average efficiency scores exhibit a bimodal distribution (see Fig. 2), i.e., most departments and capitals have an efficiency score close to 0 or 1. The efficiency score for the cities are higher than that for the departments.

As is to be expected, the correlation between average efficiency at the regional and urban levels is high (0.91). The average efficiency leaders, both at the capital city and regional levels, are Cundinamarca, Antioquia, San Andrés archipelago, Atlántico, Caldas, Risaralda and Quindío (see Fig. 3). The capital cities of these departments have an average population density of 3685 inhabitants per square kilometer, almost three times the average for the 32 capital cities (1289 inhabitants per square kilometer). On the other end of the distribution, Vichada, Vaupés, Sucre, Guaviare, Chocó, Caquetá and Cesar have the lowest average efficiency scores. The average population density for the corresponding capitals is 266 inhabitants per square kilometer, which is a fifth of the average for the 32 capital cities. These results would suggest that agglomeration is the main force behind innovation efficiency, thus confirming the first hypothesis (H1). However, there are sparsely populated cities that are highly efficient in the innovation process, e.g., Mocoa in Putumayo, with a density of 48 inhabitants per square kilometer and an average efficiency score of 0.81, or Yopal in Casanare, with a density of 65 inhabitants per square kilometer and an average efficiency score of 0.83. Moreover, there are densely populated cities that lack innovation efficiency, e.g., Cartagena, with a density of 1844 inhabitants per square kilometer and an average efficiency score of 0.49.

To further test hypothesis H1, we divided the regions and cities by capital city population density and calculated the mean RIS and UIS efficiency scores, including all available years. The results are shown in Table 3. The relation between population density and innovation efficiency appears to be monotonic. However, we conduct t-tests for the difference in mean between each quartile and the one immediately preceding it, and conclude that only the fourth quartile is significantly different from the third quartile. Thus, densely populated regions and cities are most likely highly efficient in knowledge production, but population density is not, in general, a good predictor of innovation efficiency.

Table 3. RIS and UIS efficiency by quartile of capital city population density

Quartile	Capital city pop. Density	Mean RIS efficiency	Mean UIS efficiency
1	pop/km^2 64.14	0.2767	0.3541
		(0.3088)	(0.3385)
2	65.14 pop/km^2 < 378.00	0.3976	0.4781
		(0.2664)	(0.3145)
3	378.00 pop/km^2 < 1844.46	0.5756	0.7391
		(0.2905)	(0.3198)
4	pop/km^2 1844.46	0.9152*	0.9540***
		(0.1133)	(0.0753)

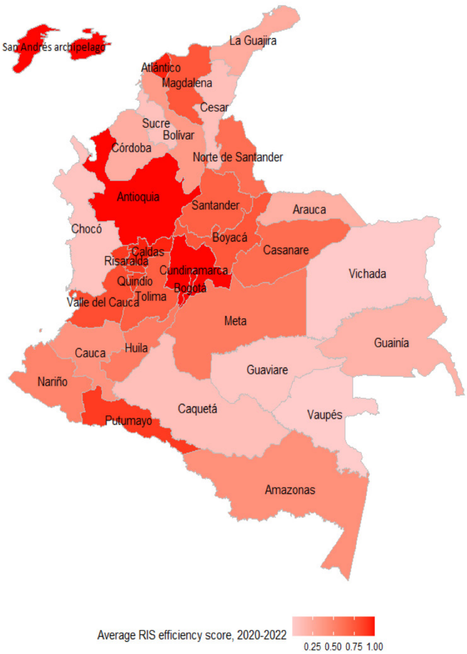
Note 1: Standard errors in parentheses.
Note 2: * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$.
Source: Authors based on CPC (2022).

Figures 1, 2, and 3 illustrate the average efficiency scores of Colombia's Regional Innovation Systems (RIS) over the period 2020–2022. The spatial distribution reveals a pronounced territorial heterogeneity in innovation performance across departments. High-efficiency regions are strongly concentrated in the country's central Andean corridor, particularly in Bogotá–Cundinamarca, Antioquia, Caldas, Risaralda, and Quindío, which together form the core of Colombia's productive and knowledge-intensive economy. These regions host the largest concentration of universities, research institutions, firms, and public agencies, facilitating dense interactions among innovation actors.

In contrast, departments located in the eastern and southeastern parts of the country—such as Vaupés, Guainía, Vichada, Guaviare, and Caquetá—exhibit substantially lower efficiency scores. These territories are characterized by low population density, limited business activity, weaker institutional capacity, and restricted access to higher education infrastructure. The observed spatial pattern suggests that innovation efficiency in Colombia is not evenly distributed, but rather reflects long-standing structural asymmetries between the country's core and peripheral regions.

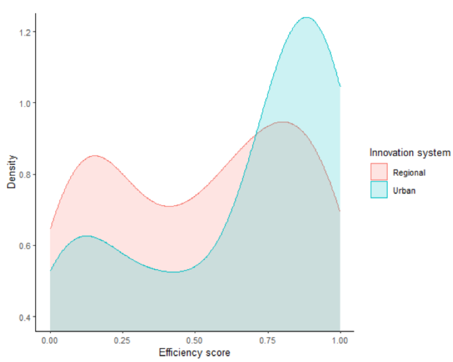
Overall, the figures highlight the existence of a strong center–periphery structure in Colombia's regional innovation system, underscoring the relevance of place-based innovation policies tailored to regional capabilities rather than uniform national interventions.

Figure 1. Average RIS efficiency scores in 2020-2022



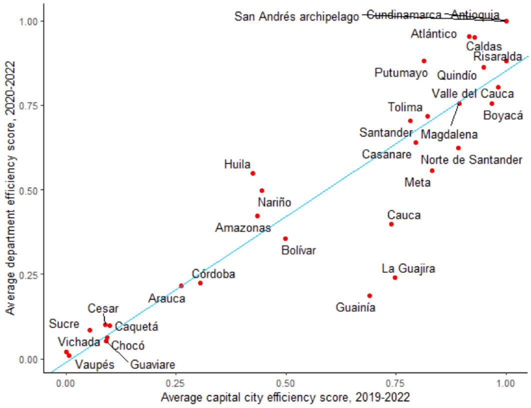
Note: Moran's I = 0.07, p-value = 0.0002.
Source: Authors based on CPC (2022).

Figure 2. Densities of average RIS and UIS efficiency scores



Source: Authors based on CPC (2022).

Figure 3. Average RIS and UIS efficiency scores



Note: Correlation between both variables is 0.91.
Source: Authors based on CPC (2022).

4.2. Determinants of innovation efficiency

Table 4 reports the results of the second-stage panel regressions examining the determinants of innovation system (IS) efficiency at both the regional (departments) and urban (cities) levels. The dependent variable is the logarithm of the efficiency scores obtained from the first-stage Data Envelopment Analysis (DEA). To account for unobserved heterogeneity, both fixed-effects and random-effects specifications are estimated for each spatial scale. The explanatory variables capture key structural components of innovation systems, including private entrepreneurial activity (business density), the presence of high-quality universities, institutional performance of the legal system, and labor market conditions measured through underemployment. All standard errors are computed using heteroskedasticity- and autocorrelation-consistent estimators that are also robust to cross-sectional dependence, ensuring reliable statistical inference in the presence of multiple forms of panel-data misspecification. Diagnostic tests are reported at the bottom of the table to assess model specification.

Table 4. Regression results for RIS and UIS efficiency factor identification

Dependent variable: log(IS efficiency score)

Factor of IS efficiency	Variables	Regional (departments)		Urban (cities)	
		Fixed effects	Random effects	Fixed effects	Random effects
Private entrepreneurs	log(Business density)	1.353***	1.415***	1.664***	1.748***
		(0.063)	(0.077)	(0.103)	(0.033)

(Continue)

Dependent variable: log(IS efficiency score)

Factor of IS efficiency	Variables	Regional (departments)		Urban (cities)	
Universities	High-quality universities coverage	0.023***	0.025***	0.017***	0.008**
		(0.003)	(0.006)	(0.001)	(0.002)
Legal system	Judicial efficiency	0.016***	0.005	0.014*	-0.002
		(0.002)	(0.005)	(0.006)	(0.006)
Workers	Underemployment rate	-0.032	-0.058	-0.074***	-0.098*
		(0.023)	(0.030)	(0.007)	(0.042)
	Constant		-3.792***		-4.012
			(0.594)		(0.735)
Breusch-Pagan LM test	0.000		0.000		
Hausman test		0.028		0.021	
Wald test		0.000		0.000	
Wooldridge test	0.000		0.000		
Cross-sectional dependence	0.000		0.296		
R-squared		0.601	0.432	0.449	0.256
N		33	33	32	32
T		2020-2022	2020-2022	2019-2022	2019-2022
Obs.		99	99	128	128

Note 1: Driscoll–Kraay standard errors in parentheses. These standard errors are robust to heteroscedasticity, autocorrelation, and cross-sectional dependence.
Note 2: * $p < 0.05$ ** $p < 0.001$ *** $p < 0.0001$.
Source: Authors based on CPC (2022).

The results of the Breusch–Pagan Lagrange multiplier test provide evidence of unobserved individual effects, indicating that pooled ordinary least squares is not appropriate. Furthermore, the Hausman test suggests statistically significant differences between the fixed-effects and random-effects estimators. Accordingly, the fixed-effects specification is adopted as the preferred model for interpretation (Table 4). The results from the Wald test and Wooldridge tests confirm the presence of heteroscedasticity and autocorrelation, respectively. Lastly, the results from the cross-sectional dependence test show there is cross-sectional dependence between cities, but not between regions.

An increase of 1% in business density is associated with an increase in innovation efficiency of 1.4% at the regional level and 1.7% at the urban level. These magnitudes are considerably larger than those reported by Zemtzov and Kotsemir (2019) for Russian regions, suggesting that entrepreneurial density may play a particularly important role in middle-income economies such as Colombia. Economically, this result reflects the dual role of firms in innovation systems. On the one hand, higher firm density intensifies competitive pressures, incentivizing innovation as a strategy for market differentiation. On the other hand, it facilitates cooperation and knowledge exchange, particularly between small and medium-sized enterprises and larger firms with established technological capabilities (Zahoor and Al-Tabbaab, 2020).

From a policy standpoint, these findings indicate that innovation policy cannot be detached from productive development policy. Instruments that promote firm creation, formalization, and local business ecosystems—such as entrepreneurial support programs, cluster policies, and access to finance—may significantly enhance innovation efficiency even without large increases in R&D spending.

The results show that an increase of one percentage point in high-quality university coverage leads to an increase in innovation efficiency of approximately 2.3% for regional innovation systems (RIS) and 1.7% for urban innovation systems (UIS). This finding highlights that innovation efficiency is not driven solely by the physical presence of universities, but rather by their capacity to integrate students into high-quality higher education institutions within the territory. From an economic perspective, this result underscores the role of universities as mechanisms that strengthen regional absorptive capacity, enabling territories to transform research inputs into economically relevant technological outputs more effectively. In policy terms, this implies that innovation strategies should prioritize not only expanding higher education infrastructure, but also improving quality accreditation processes and reducing barriers to student access. Policies that increase enrollment in high-quality institutions—such as regional scholarship programs or territorial expansion of accredited universities—may therefore yield substantial efficiency gains in innovation systems.

Judicial efficiency exhibits a positive and statistically significant effect on innovation efficiency, with a one percentage point increase leading to an efficiency gain of approximately 1.6% and 1.4% at the regional and urban levels, respectively. This result is consistent with Feng et al. (2021), who emphasize the role of legal institutions in reducing uncertainty and protecting property rights, thereby encouraging knowledge formalization through patents. Efficient judicial systems contribute to a stable environment in which innovation investments become less risky and more predictable. From a policy perspective, the finding highlights the importance of institutional strengthening as a long-term innovation strategy. Improvements in judicial performance—such as faster dispute resolution mechanisms and greater legal certainty—may not immediately increase patenting at the firm level, but they enhance the overall efficiency with which regional innovation systems transform inputs into technological outputs.

Lastly, the results indicate that a one percentage point increase in the underemployment rate reduces urban innovation efficiency by approximately 7.4%, while no statistically significant effect is observed at the regional level. This asymmetry suggests that labor-market conditions play a more direct role in cities, where innovation processes are more strongly embedded within firms and organizational structures.

This finding supports the “happy–productive worker” hypothesis, according to which dissatisfied workers exhibit lower levels of engagement, creativity, and knowledge sharing (Wright et al., 2007; Ayala et al., 2017). In urban innovation systems, where innovation largely occurs through firm-level interactions, worker dissatisfaction may therefore directly undermine innovative performance. In policy terms, the result implies that innovation policy cannot rely exclusively on technological or financial instruments. Labor-market quality —including job stability, adequate remuneration, and skill matching— constitutes a complementary condition for innovation efficiency. Urban development strategies that reduce precarious employment may thus indirectly enhance innovation outcomes.

5. Conclusion

This study analyzed the efficiency of regional and urban innovation systems in Colombia by applying a two-stage methodology that combines Data Envelopment Analysis and panel-data econometric models. By evaluating how departments and capital cities transform innovation-related inputs into technological outputs, the paper provides new evidence on the structural determinants of innovation efficiency in a highly heterogeneous upper-middle-income economy.

The results reveal a pronounced territorial asymmetry in Colombia's innovation system. A small group of regions and cities—primarily Bogotá and Antioquia—exhibit consistently high efficiency scores, while a substantial share of territories display efficiency levels close to zero. This pattern reflects the strong spatial concentration of knowledge-generating institutions, business activity, and institutional capacity, and confirms that innovation in Colombia remains deeply centralized despite decades of regional development policies.

Taken together, the empirical findings highlight three central mechanisms shaping innovation efficiency in the Colombian context. First, human capital formation through high-quality universities emerges as a key driver of efficiency. Regions and cities with broader coverage of accredited higher education institutions are substantially more capable of converting existing inputs into technological outputs. This result is particularly relevant for Colombia, where most high-quality universities remain geographically concentrated: more than half are located in Bogotá and Antioquia, while several departments lack any accredited institution. These disparities suggest that innovation gaps are not merely technological, but fundamentally educational and institutional in nature.

Second, private entrepreneurship plays a central role in strengthening innovation efficiency. Business density exhibits a robust positive association with efficiency at both regional and urban levels, underscoring the importance of productive ecosystems in which firms interact, compete, and cooperate. In the Colombian case—characterized by high levels of firm informality and uneven entrepreneurial development—this result emphasizes that innovation policy cannot be decoupled from policies that foster firm creation, formalization, and local productive networks. Strengthening entrepreneurial ecosystems may yield substantial innovation gains even in the absence of large increases in R&D expenditure.

Third, institutional and labor-market conditions significantly shape innovation outcomes. Judicial efficiency contributes positively to both regional and urban innovation efficiency, highlighting the importance of legal certainty and effective protection of intellectual property rights as system-level enablers of innovation. At the urban level, worker dissatisfaction—proxied by underemployment—exerts a strong negative effect on innovation efficiency, suggesting that creative and intrapreneurial activities depend critically on labor-market quality. In Colombia, where underemployment remains persistently high in many cities, this finding reinforces the idea that innovation policy must incorporate social and labor dimensions alongside technological instruments.

From a policy perspective, the results point to a central trade-off in the design of innovation strategies. While efficiency-based concentration of R&D funding may maximize short-term output, it risks reinforcing existing territorial inequalities. A strictly selective approach could further marginalize regions that already lack universities, firms, and institutional capacity. Instead, this study suggests that a proportional allocation of innovation resources—linked to efficiency levels but not exclusively determined by them—may foster convergence in knowledge production while preserving incentives for performance improvements.

In the long term, reducing Colombia's innovation gap requires structural investments in higher education quality beyond the traditional innovation hubs, particularly in the southeastern regions of the country. In the short and medium term, improving judicial performance and labor-market conditions may represent more immediately actionable levers for increasing innovation efficiency. Together, these findings underscore that innovation in developing economies is not solely a matter of R&D intensity, but of territorial capabilities shaped by education, entrepreneurship, institutions, and workforce well-being.

From a theoretical perspective, the results reinforce the systemic interpretation of the Triple Helix model, according to which innovation outcomes emerge not from isolated actors but from the coordinated interaction between universities, firms, and public institutions. Recent contributions emphasize that the effectiveness of innovation systems depends on the balance and complementarity among helices, rather than the dominance of any single one (Ranga and Etzkowitz, 2013; Cai and Etzkowitz, 2020; Carayannis et al., 2018).

The Colombian case illustrates this systemic logic clearly. Regions and cities exhibit higher innovation efficiency when strong academic institutions coexist with dense entrepreneurial ecosystems and institutional environments capable of protecting intellectual property. At the same time, the relevance of intrapreneurship highlights the importance of organizational dynamics within firms, reinforcing recent extensions of the Triple Helix that stress micro-level mechanisms linking institutions to innovation performance. Taken together, the findings support a view of innovation policy as a coordinated, place-based strategy that strengthens interactions across institutional spheres rather than focusing on single policy instruments.

This study is subject to several limitations that should be acknowledged. First, the analysis relies on a relatively short panel due to data availability constraints, which limits the exploration of long-run dynamics in innovation efficiency. Second, although Data Envelopment Analysis provides a flexible and non-parametric measure of efficiency, results may be sensitive to the choice of inputs and outputs, as well as to the absence of statistical noise in the first-stage estimation. Third, some explanatory variables—such as judicial efficiency and intrapreneurship—are necessarily proxied using available administrative indicators, which may not fully capture the underlying institutional or organizational processes.

These limitations also open promising avenues for future research. Further studies could extend the analysis using longer time horizons as new data become available, explore dynamic efficiency models, or incorporate spatial econometric techniques to explicitly model interregional knowledge spillovers. Future work could also integrate additional helices—such as civil society or environmental sustainability—in line with emerging Quadruple and Quintuple Helix frameworks. Finally, combining quantitative efficiency analysis with qualitative case studies at the regional level would allow a deeper understanding of how institutional interactions translate into concrete innovation outcomes.

Overall, this study contributes to the literature by providing one of the first integrated efficiency-based analyses of regional and urban innovation systems in Colombia. By explicitly linking innovation efficiency to territorial structures, it offers a framework for understanding why innovation disparities persist and how policy design can better address them in spatially unequal economies.

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Appendix

Table 5. Average UIS efficiency scores in the studied Colombian capital cities.

City	2019	2020	2021	2022	Avg. 2019-2020
Bogotá D.C.	1.000	1.000	1.000	1.000	1.000
Medellín	1.000	1.000	1.000	1.000	1.000
Pereira	1.000	1.000	1.000	1.000	1.000
San Andrés	1.000	1.000	1.000	1.000	1.000
Cali	0.981	0.949	1.000	1.000	0.982
Tunja	1.000	0.875	1.000	1.000	0.969
Armenia	1.000	0.799	1.000	1.000	0.950
Manizales	0.756	1.000	1.000	0.959	0.929
Barranquilla	0.665	1.000	1.000	1.000	0.916
Santa Marta	0.574	1.000	1.000	1.000	0.894
Cúcuta AM	1.000	1.000	0.856	0.712	0.892
Villavicencio	1.000	0.618	1.000	0.714	0.833
Ibagué	0.472	0.813	1.000	1.000	0.821
Mocoa	1.000	1.000	1.000	0.251	0.813
Yopal	0.183	1.000	1.000	1.000	0.796
Bucaramanga	0.590	0.591	0.953	1.000	0.784
Riohacha	0.030	1.000	1.000	0.963	0.748
Popayán	0.300	0.800	0.864	0.992	0.739
Inírida	0.000	0.763	1.000	1.000	0.691
Cartagena	0.523	0.389	0.471	0.611	0.498
Pasto	0.225	0.559	0.602	0.391	0.444
Leticia	0.335	0.246	0.160	1.000	0.435
Neiva	0.123	0.142	0.543	0.889	0.424
Montería	0.399	0.273	0.270	0.280	0.305
Arauca	0.084	0.056	0.104	0.803	0.262
Florencia	0.128	0.107	0.109	0.051	0.099
Quibdó	0.106	0.088	0.046	0.131	0.093
San José del Guaviare	0.033	0.027	0.034	0.268	0.090
Valledupar	0.091	0.066	0.048	0.152	0.089
Sincelejo	0.061	0.040	0.039	0.076	0.054
Mitú	0.030	0.000	0.000	0.000	0.008
Puerto Carreño	0.000	0.000	0.000	0.000	0.000

Source: Authors based on CPC (2022).

Table 6. Average RIS efficiency scores in the studied Colombian regions in 2020-2022.

Department	Capital city	2020	2021	2022	Avg. 2020-2022
Antioquia	Medellín	1.000	1.000	1.000	1.000
Archipiélago de San Andrés	San Andrés	1.000	1.000	1.000	1.000
Bogotá, D.C.	Bogotá, D.C.	1.000	1.000	1.000	1.000
Cundinamarca	Bogotá, D.C.	1.000	1.000	1.000	1.000
Atlántico	Barranquilla	0.856	1.000	1.000	0.952
Caldas	Manizales	0.930	0.925	1.000	0.952
Putumayo	Mocoa	0.645	1.000	1.000	0.882
Risaralda	Pereira	0.866	1.000	0.775	0.880
Quindío	Armenia	0.808	0.781	1.000	0.863
Valle del Cauca	Cali	0.704	0.851	0.852	0.802
Magdalena	Santa Marta	0.775	0.684	0.808	0.756
Boyacá	Tunja	0.957	0.620	0.689	0.755
Tolima	Ibagué	0.425	0.730	1.000	0.718
Santander	Cúcuta	0.635	0.598	0.880	0.705
Casanare	Yopal	1.000	0.426	0.492	0.639
Norte de Santander	Cúcuta	0.697	0.565	0.611	0.624
Meta	Villavicencio	0.571	0.507	0.591	0.556
Huila	Neiva	0.444	0.483	0.717	0.548
Nariño	Pato	0.454	0.575	0.462	0.497
Amazonas	Leticia	0.191	0.075	1.000	0.422
Cauca	Cauca	0.285	0.472	0.438	0.399
Bolívar	Cartagena	0.565	0.230	0.272	0.356
La Guajira	Riohacha	0.035	0.287	0.399	0.241
Córdoba	Montería	0.281	0.200	0.192	0.225
Arauca	Arauca	0.194	0.132	0.319	0.215
Guainía	Inírida	0.000	0.069	0.489	0.186
Cesar	Valledupar	0.123	0.100	0.077	0.100
Caquetá	Florencia	0.129	0.108	0.055	0.097
Sucre	Sincelejo	0.083	0.075	0.094	0.084
Chocó	Quibdó	0.071	0.060	0.061	0.064
Guaviare	San José del Guaviare	0.019	0.023	0.115	0.052
Vichada	Puerto Carreño	0.000	0.000	0.064	0.021
Vaupés	Mitú	0.028	0.000	0.000	0.009

Source: Authors based on CPC (2022).