HETEROGENEITY IS THE RULE, NOT THE EXCEPTION? A TENTATIVE TYPOLOGY OF NATIONAL INNOVATION SYSTEMS

Pedro Luiz Costa Cavalcante[1]

The inquiry departs from the idea that heterogeneity is the rule, not the exception, regarding the National Innovation Systems (NIS) worldwide. The paper's main goal is to advance understanding with empirical-based knowledge on how this uneven pattern occurs by formulating an original typology of NIS that surpasses the continental boundaries analysis and, primarily, highlights the strengths of few and weaknesses of most nations. Using the Global Innovation Index (GII), the paper employs descriptive analysis, bivariate correlation, and variance analysis, followed by clustering. The cluster analysis created five types of NIS that displayed an even more accurate description of how innovative countries are, beyond the income or continent cohorts. This original and comprehensive approach to the NIS disparities is crucial to advancing in how few countries continue to improve their innovative performance. At the same time, most countries keep struggling to increase innovation capacity to overcome their economic underdevelopment issues.

Keywords: innovation; comparative analysis; state capacity; economic development, world.

A HETEROGENEIDADE É A REGRA, NÃO A EXCEÇÃO? UMA PROPOSTA DE TIPOLOGIA PARA OS SISTEMAS NACIONAIS DE INOVAÇÃO

O artigo parte da ideia de que a heterogeneidade é a regra, não a exceção, nos Sistemas Nacionais de Inovação (SNIs) em todo o mundo. O objetivo principal do artigo é avançar na compreensão com base em dados empíricos sobre como esse padrão desigual ocorre, a partir da formulação de uma tipologia original de SNI que ultrapasse a análise das fronteiras continentais e, principalmente, destaque os pontos fortes de poucos e os pontos fracos da maioria das nações no campo da inovação. Utilizando o Índice de Inovação Global (IIG), o trabalho emprega análise descritiva, correlação bivariada e análise de variância, seguida de clusterização. A análise de *cluster* criou cinco tipos de SNI que apresentaram uma descrição ainda mais precisa de como os países se estruturam e são inovadores, além dos recortes de renda ou continente. Essa abordagem original e abrangente das disparidades do SNI é crucial para avançar em como poucos países continuam a melhorar seu desempenho inovador, ao mesmo tempo que a maioria dos países continua lutando para aumentar a capacidade de inovação e, assim, superar seus problemas de subdesenvolvimento econômico.

Palavras-chave: inovação; análise comparativa; capacidade estatal; desenvolvimento econômico; mundo.

¿ES LA HETEROGENEIDAD LA REGLA, NO LA EXCEPCIÓN? UNA PROPUESTA DE TIPOLOGÍA PARA LOS SISTEMAS NACIONALES DE INNOVACIÓN

El artículo parte de la idea de que la heterogeneidad es la regla, no la excepción, en los Sistemas Nacionales de Innovación (SNIs) alrededor del mundo. El objetivo principal del artículo es avanzar

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en la comprensión basada en datos empíricos acerca de cómo se produce este patrón desigual, a partir de la formulación de una tipología original de SNI que va más allá del análisis de las fronteras continentales y, principalmente, destaca las fortalezas de unos pocos y las debilidades de la mayoría de las naciones en el campo de la innovación. Utilizando el Índice de Innovación Global (IIG), el trabajo emplea análisis descriptivo, correlación bivariada y análisis de varianza, seguido de agrupamiento. El análisis de conglomerados creó cinco tipos de SNI que presentaban una descripción aún más precisa de cómo los países están estructurados e innovadores, además de los recortes de ingresos o continentes. Este enfoque original e integral de las brechas SIN es crucial para avanzar, ya que pocos países continúan mejorando su desempeño innovador. Al mismo tiempo, la mayoría de los países continúan luchando por incrementar su capacidad de innovación y así superar sus problemas de subdesarrollo económico.

Palabras clave: innovación; análisis comparativo; capacidad estatal; desarrollo económico; mundo.

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1 INTRODUCTION

Innovation has gathered a high level of attention among scholars and policymakers globally because it is one of the most critical drivers for economic progress and competitiveness in developed and developing countries (Cirera and Maloney, 2017; Cirera et al., 2020). Innovations, meaning new products, services, processes, or business models used commercially or non-commercially, can contribute to solutions for urgent societal challenges (Edler and Fagerberg, 2017) and improve citizens' welfare, as the covid-19 vaccination has shown.

Considering its relevance and the dynamic challenges of the contemporary world, strengthening a nation's innovation systems has become crucial for economic growth, measured by the gross domestic product (GDP) and strategy to reach inclusive and sustainable development (Kattel and Mazzucato, 2018). This new model of development innovation-led relies on government acts as a catalyst in creating and shaping markets through dynamic public-private partnerships (Mazzucato, 2013) as well as designing and implementing coherent policy mixes (instruments and funding) and capabilities to coordinate them (Cirera et al., 2020).

Despite this relative consensus, firms and governments' innovation challenges and their deliberative strategies result in different stages of the innovation systems. A National Innovation System (NIS) encompasses various institutions supporting and orienting the dynamics of economic activity where innovation is the key driving force (Lundvall, 2010). The primary function of the NIS is to promote interactive learning, encompassing individual, organizational, and inter-organizational levels, that should generate positive feedback and by reproduction, and link innovation capabilities to economic development (Lundvall, 2016; Nelson, 2016). However, while some nations have built a structured or mature system with well-functioning institutions, policies, and actors' interactions, in most countries, systemic failure prevails. In other words, the situation in which the economy lacks the fundamental building blocks that can support the creation, absorption, use, and dissemination of practical knowledge through interactive learning (Lundvall et al., 2009).

This heterogeneity can be noticed among countries and world regions (Lastres and Cassiolato, 2005; Lundvall, Intarakumnerd and Vang, 2006; Lundvall et al., 2009; Adebowale et al., 2014). The unevenness patterns of innovation include governments that have historically placed it at the center of their growth strategies, as Western developed economies. In the meantime, East Asian countries compete for top positions in innovation rankings after experiencing a period of catch-up and growth. On the other extreme, most countries are still struggling to build innovative capabilities to increase manufacturing, service, or agriculture value chain toward higher-value-added activities. This group also keep facing the well-known middle-income growth traps, i.e., the situation when economies are stuck on the intermediate level incapable of upgrading to the high-income level and characterized by i) low investment ratios; ii) slow manufacturing growth; iii) limited industrial diversification; and iv) poor labor market conditions (Agénor, Canuto and Jelenic, 2012).

Despite the relevance of the debate about innovation and economic development and the notorious heterogeneity among nations, few studies have properly explored this diversity. The bulk of the literature focuses on case studies or small *N* comparative analysis (Lundvall et al., 2009; Lundvall, 2010; 2016; Iootty, 2019; Reynolds, Schneider and Zylberberg, 2019). In this context, a fertile research field is open to investigating this asymmetric scenario. What is the actual difference among countries and regions regarding their innovation system's structure and achievement? Which dimensions of their NIS reside the higher disparities? What is the level of performance disparity among countries in the same region? Are the continents and the level of development the most accurate aggregation criteria for understanding the countries' heterogeneity in innovation?

The paper compares nations' innovation systems worldwide, including their inputs dimensions and innovative performance, to explore these crucial questions. The inquiry departs from the idea that heterogeneity is the rule, not the exception regarding the NIS. However, its purpose is to advance understanding with empirical-based knowledge on how this uneven pattern occurs. By addressing comparatively different perspectives of countries' innovative structure and performance, the paper's main goal is to formulate an original typology of NIS that surpasses the continental boundaries analysis and, primarily, highlights the strengths of few and weaknesses of most nations. This typology contributes to improving the academic debate in the field of study and providing information and insights to countries' policymakers and leaders about the diagnostic of their NIS and the path their policies must face.

The comparative approach uses primary data from the Global Innovation Index (GII) that annually ranks approximately 130 countries based on a comprehensive and sophisticated analysis of their innovation inputs and outputs (Dutta, Lanvin and Wunsch-Vincent, 2020). To do so, the inquiry employs exploratory descriptive analysis, bivariate correlation, and analysis of variance (Anova), followed by clustering to identify similar groups and propose a tentative NIS typology beyond the continent and the level of development criteria.

The remainder of the paper is as follows: the inquiry discusses the NIS literature that highlights the key dimensions to understanding how the economies are organized and their performance in the innovation field. The third section presents the methodological steps. The following empirically addresses the differences in the innovation inputs and outputs among countries by GDP level, continents, and the results of the clusters analysis. Lastly, some final remarks are debated.

2 NATIONAL INNOVATION SYSTEM'S LITERATURE

Despite the relative consensus on the correlation between innovation and development, the same is not observed regarding how to build a dynamic and vibrant innovative economy with innovation-led policies aimed at promoting structural economic change. In this sense, industrialization and structural change grounded in innovation-led strategies are the key sources to poverty reduction, sustained and rapid economic growth (Lin, 2012). This process focuses primarily on technological innovation and industrial advances and diversification, also called technology upgrading. It is an outcome of the interaction between the intensification and breadth of different types of technology activities; structural factors and changes in this process are mediated by how the economy interacts with the global economy (Radosevic and Yoruk, 2018). According to Lacasa et al. (2019), the multidimensionality feature of this process can be portrayed by quantitative initiatives, such as the Global Competitiveness Index or the GII.

These indexes also reveal essential components and characteristics of countries' innovative capability, i.e., the ability of a country to produce and commercialize a flow of innovative technology over the long term as drivers of economic growth and competitiveness (Castellacci and Natera, 2013; 2016). An analysis of the innovation system and its successful results may also rely on a broad view of innovation policy and investing in missing complementary factors within the nation, including institutions, knowledge, human capital and research (HC&R), financial resources, infrastructure, among others (Iootty, 2019).

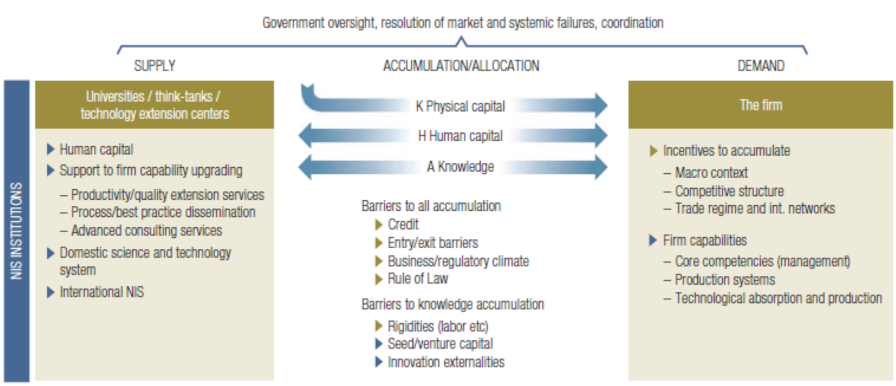
This holistic perspective helps to understand the innovation system and its role in the social and economic development of the countries.

This theoretical debate is influenced by Schumpeterian and evolutionary perspectives and grounded in the NIS literature, which leaves little room for the idea of an 'optimal' state and is openly skeptical with the government interference restricted to market failure (Fagerberg, 2017; Lundvall, 2016; Mazzucato, 2013). The NIS approach emerged during the late 1980s and early 1990s and has become popular since then among policymakers willing to generate scientific knowledge, technology, and innovation (Edler and Fagerberg, 2017). The innovation system means two complementary concepts: i) a tool for designing innovation policy; and ii) an analytical framework for scholars to assess innovation policies and their results.

In short, the country or regional innovation system is an arrangement of interactions between firms and entrepreneurs with bounded rationality and institutions that are in constant evolution. In this approach, as public policies and programs are not only an essential part of the engine but inevitably (Nelson, 2016), governments must be planned, designed, and implemented innovation initiatives systematically and in a dynamic way (Cirera and Maloney, 2017).

Moreover, the comprehensive view of the phenomenon goes beyond the focus on research and development (R&D). It includes other dimensions of analysis in the innovation system, such as the labor market, education system, financial institutions, regulatory structures, and other institutions that shape economic dynamics. Figure 1 below shows the NIS framework with its institutions and three dimensions – supply, accumulation/allocation and demand.

FIGURE 1
The National Innovation System

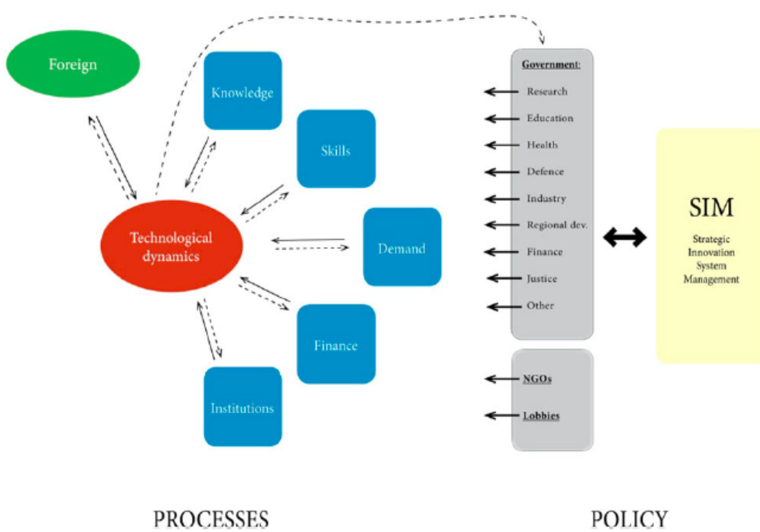


Source: Cirera and Maloney (2017).
Obs.: Figure displayed in low resolution and whose layout and texts could not be formatted and proofread due to the technical characteristics of the original files (Publisher's note).

The system elements tend to reflect on how the innovation capabilities are structured and its level of accomplishment, which may also be influenced by a variety of other factors, such as historical experience, language, culture, and so on. Undoubtedly, as much of technology is science-based, the education system, research and financial systems are also vital.

The dynamism and interactive features of innovation are also essential to gather different parts of the system together to pursue innovation, diffusion and use of technology. According to Fagerberg (2017), in a complementary approach, this output is named "technological dynamics" and, is constantly affected by five generic processes in the NIS: knowledge, skills, demand, finance and institutions. As illustrated in figure 2, the feedbacks and influences are in both directions. They include interactions between various actors/sectors in and outside the government involved in the policymaking. The characteristics, ideas, goals and level prioritization of this process, labeled "strategic innovation system management", also vary for each NIS and affect the economies' capacity and performance (Fagerberg, 2017).

FIGURE 2
NIS dynamics, processes and policy



Source: Fagerberg (2017).
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The success of this strategic innovation system management in fostering innovative outputs is very challenging, correlated to the country's economic system (industries, firms etc.) and the political and institutional design. Countries face these challenges grounded in different strategies and conditions that may result in various stages of the NIS: between the mature (well-functioning) and the systemic failure. The latter occurs whenever emerging innovation systems lack the building blocks needed to create, absorb, use, and disseminate practical knowledge through interactive learning (Lundvall et al., 2009). It usually happens in developing nations also trapped with structural issues, such as poverty and inequality, where resources are limited and managers can carry out these programs and policy measures are scarce (Cozzens and Kaplinsky, 2009; World Bank, 2010).

It seems to be the case of the innovation paradox, i.e., despite the well-known potential returns to innovation, most governments in emerging nations cannot formulate and implement policies properly and build an institutional environment to reach high-tech or industrial economic development (Cirera et al., 2020). According to Cirera and Maloney (2017), these barriers are not a matter of some irrationality on the part of firms and governments, but a typical innovation policy dilemma.

> The greater magnitude of the market failures to be resolved and the multiplicity of missing complementary factors and institutions increase the complexity of innovation policy; at the same time, governments' capabilities to design, implement, and coordinate an effective policy mix to manage it are weaker (Cirera and Maloney, 2017, p. 111).

So, this literature agrees that the low innovation activity observed in most developing countries has multiple causes. Most importantly, the failures can be related to a wide range of complementarities factors that are dynamic interactive (Fagerberg, 2017; Cirera and Maloney, 2017). To overcome this situation, World Bank (2010, p. 3) suggests a long-term strategy based on the philosophy of radical gradualism; in other words, "a sequence of finely tuned small, specific reforms and successful outcomes that paves the way for broader, institutional changes".

However, suppose much attention has been devoted to investigating the multidimensional features of the innovation systems and how policy must be designed and implemented to promote innovative culture in firms and public organizations. In that case, it also seems relevant to deepen the research on comparing how the NIS are effectively doing. The countries' heterogeneity worldwide is also a consensus in the literature, but most of the studies focus on specific NIS or intraregional analysis, such as in Latin America (Lastres and Cassiolato, 2005), Asia (Lundvall, Intarakumnerd and Vang, 2006) and Africa (Adebowale et al., 2014).

Although there is no 'one fits all' recipe for nurturing innovation culture or the ideal type of innovation system, the comparative analytical approach contributes to innovation and development studies by providing a broad and accurate diagnosis on the NIS framework, how the economy is performing compared to their peers, and their strengths and weaknesses.

In sum, an understanding of the innovation system and its results typically evolves through interaction between a country's economic system and its political and institutional framework and the financial system and business regulation (Edler and Fagerberg, 2017; Lundvall, 2016; Nelson, 2016). By comparing the innovation inputs and outputs of a vast set of countries, the paper provides insights regarding their gaps, levels of disparity among them, and in each of the innovation dimensions. Thus, the following section explores the nations' innovation structure and performance under different perspectives.

3 METHODS

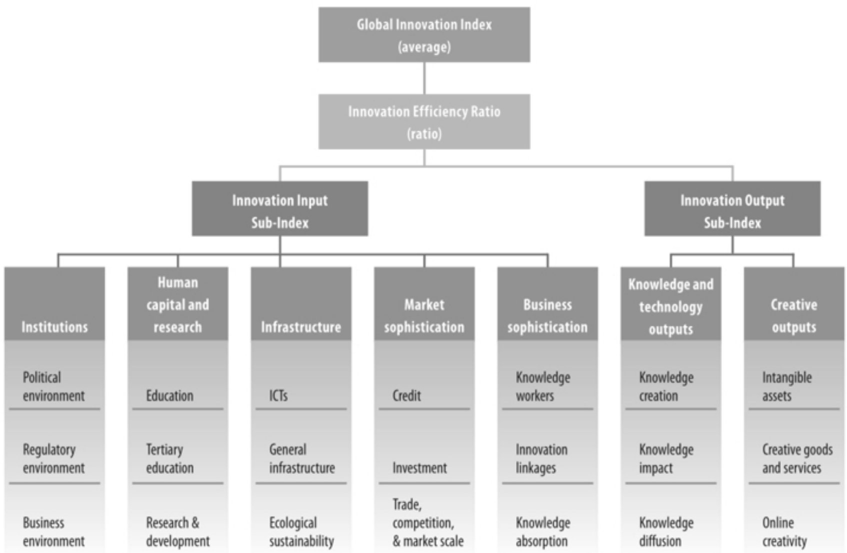
An accurate comparative analysis of innovation systems demands broad and diversified approaches. This paper is a result of quantitative research that employs descriptive and statistical methods to explore a database regarding how countries' innovation pillars have been organized and performing. After describing the GIIs framework, the paper advances on the empirical analysis. First, the indexes are correlated with the countries' income levels, using GII's score values (2019) against the GDP per capita (2018) to reinforce the assumption that relates mature NIS with economic development.

Then, the paper explores descriptively how countries are structured and performing in their innovation activities and the disparities between inter and intra continents. To do so, we first employed exploratory data analysis, focused on the indexes' average and standard variation, followed by Anova to test the group means for statistical significance. The empirical results are depicted in line, box plot and radar graphs.

Lastly and, most important, the inquiry employs cluster analysis to classify types of NIS, based on the seven indicators of innovation structure (GII inputs) and performance (GII outputs), which has many goals in searching for "natural" structure among the observations based on a multivariate profile. According to Kaufman and Rousseeuw (1990, p. 1) cluster analysis is "the art of finding groups in data". This technique aims to maximize the high internal homogeneity of countries' innovation systems within the clusters while also maximizing the high external heterogeneity (Hair et al., 2006). By exploring these patterns, the inquiry formulates a tentative taxonomy to describe how different economies are in their innovation systems.

In this sense, the GIIs was chosen because most updated and comprehensive database about NIS worldwide. It is a product of a joint partnership led by Cornell University, Institut Européen d'Administration des Affaires (Insead), and the World Intellectual Property Organization (Wipo) that, since 2013, annually published the ranking with about 130 countries.[2] The GII encompasses eighty indicators, single and composite, from different sources[3] and meaning. The following figure depicts the index, sub-indexes, and main indicators.

FIGURE 3
The Global Innovation Index



Source: GII.
Obs.: Figure displayed in low resolution and whose layout and texts could not be formatted and proofread due to the technical characteristics of the original files (Publisher's note).

To capture innovation as it happens worldwide, the GII divides into two dimensions or sub-indexes. The overall GII score is the average of the input and output sub-indices, and they vary in terms of scores (scale from 0 to 100) and ranks.

1) Innovation Input Sub-Index captures the main components of the national political economy relevant to the innovative activities and is divided into five pillars:

   a) institutions: the institutional framework of an economy (political, regulatory and, business environments);

2. It is worth mentioning that the GII was created in 2007, but only after 2013 the countries' indexes are publicly available.
3. For detailed information regarding the GII conceptual framework and data sources, see what is available at: <https://www.globalinnovationindex.org/Home>.

b) HC&R: level and standard of education and research activity (education, tertiary education and research and development);

c) infrastructure: including indicators of information and communication technologies (ICTs), general infrastructure, and ecological sustainability;

d) market sophistication: credit, investment environment, access to the international market, competition, and market scale tend to be essential for businesses and innovation; and

e) business sophistication: to assess how conducive firms are to innovation activity involving knowledge workers, innovation linkages and knowledge absorption.

2) Innovation Output Sub-Index meaning results from the innovation activities (above) within the economy's two pillars:

a) knowledge and technology outputs (KTOs): covering variables that are results of inventions and innovations (knowledge creation, knowledge impact and, knowledge diffusion); and

b) creative outputs (COs): to encompass the NIS dimension of creativity, the pillar has three sub-pillars: intangible assets, creative goods and services and, online creativity.

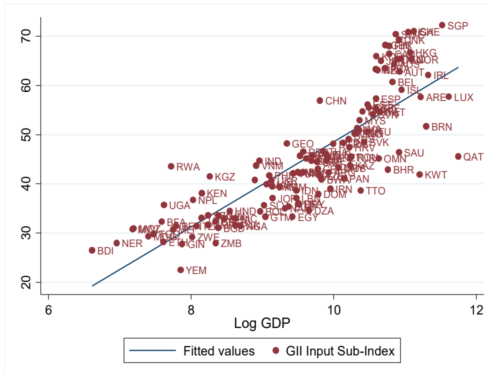
4 INNOVATION STRUCTURE AND PERFORMANCE: EMPIRICAL ANALYSIS AND DISCUSSION

4.1 Innovation and economic level

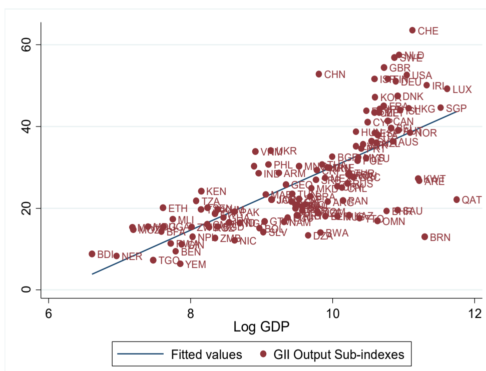
The level of maturity and sophistication of the innovation system tend to correlate with the country's economic development. A straightforward way to test that assumption is by analyzing the relations of the nations' innovation indexes and their GDP. The figures below show this relationship, including the overall GII and the input and output sub-indexes.

Figure 4 plots counties' GII score values (2019) against the GDP per capita (2018). The results confirm that innovation structure and performance increase with income per capita since the top ranks are often high-income countries. Although six of them are from the Middle East (Bahrain, Kuwait, Omar, Qatar, Saudi Arabia, and the United Arab Emirates), economies that are large oil-related GDP, stand out for their below-average GII indexes. On the other extreme, several African and Asian nations occupy the low left side of the graphs. They are low-income economies with immature NIS and poor performance in this particular matter.

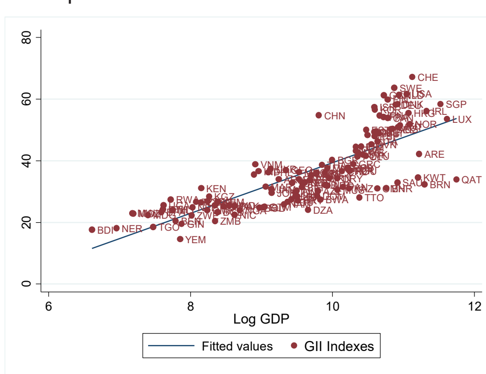
FIGURE 4
Relationship between countries' GII and GDP
4A – Countries' GII versus GDP



4B – Countries' GII input versus GDP



4C – Countries' GII output versus GDP



Source: Global Innovation Index, 2019, and Total Economy Database, 2018.
Author's elaboration.
Note: Figure whose layout and texts could not be formatted and proofread due to the technical characteristics of the original files (Publisher's note).

China is an interesting case, especially in the innovation output. Although it is still considered a developing economy, its performance is among the top five countries, only behind Switzerland, the Netherlands, Sweden, and the United Kingdom, and above the United States and Germany. In the intermediate group, the developing middle-income countries, most from East Asia and Latin America populate the graphs' center, such as Vietnam, Malaysia and Chile, the best rank among their peers.

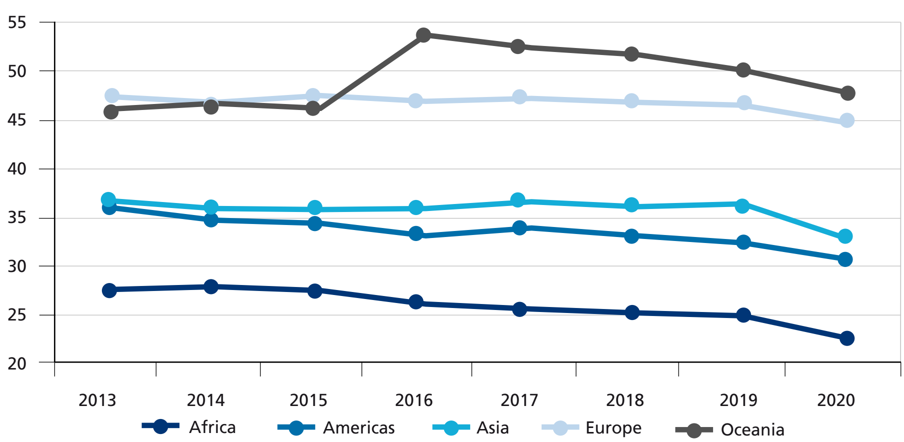
Overall, the lines in each graph indicate how correlated these two economic dimensions are. However, the results show different patterns. While in GII input the correlation reaches almost 70% (coefficient of determination - R2), in the performance indexes, it drops to only 50%, turning the average, i.e., the correlation between the general GII and the GDP slightly over 60%. In short, there is some degree of relationship in this type of approach. Nonetheless, it does not seem so straight it would be expected.

4.2 National Innovation Systems by continent

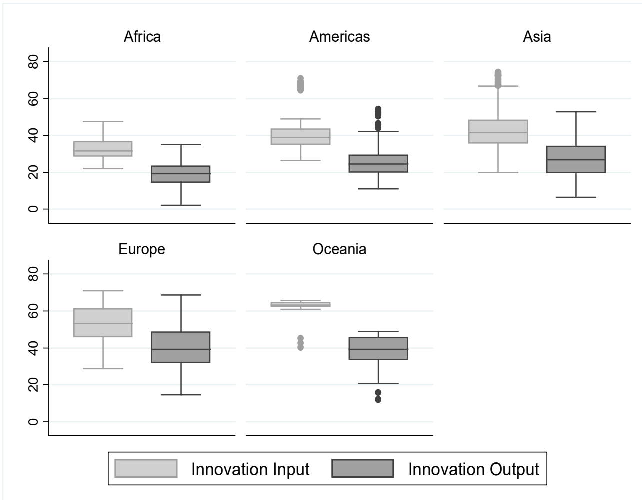
To begin with, the paper analyzes cross-regionally both sides of the innovation systems: the pillars related to the structure (inputs) followed by the performance (outputs), i.e. the results from the innovation activities. Figures 5 show how the GII changed since it was created in 2013 and the economies' sub-indexes distribution among regions (box plot).

FIGURE 5
GII's evolution and GII input/output, by continent (2013-2020)

5A – GII's evolution



5B – GII input/output



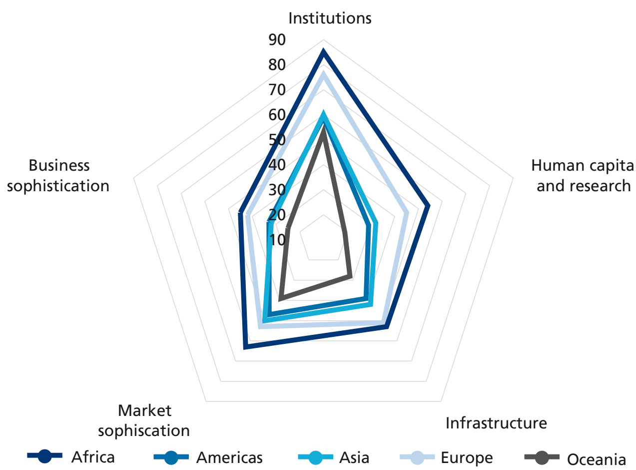
Source: GII.
Author's elaboration.
Obs.: Figure whose layout and texts could not be formatted and proofread due to the technical characteristics of the original files (Publisher's note).

The line graph presents interesting insights. First, in general, innovation systems are quite different among continents, with Oceania and Europe always in the lead. On the other extreme, Africa and Asia have the worst scores on average. Their GII means have decreased over the analyzed period, which may be related to the methodological changes as it is not reflected in their position modification, except for the top ones before 2016. It is also worth highlighting that the gaps among the continents show different patterns. In previous years, Oceania and Europe and Asia and the Americas were ranked more closely. However, Africa seems to be continuously falling behind in the innovation race.

The second graph details the GII two sub-indexes in the form of a box plot, which helps compare the regions' and how are heterogeneity the countries scores inside their continents. Overall, the same ranks discussed above prevails in both input and output dimensions; however, the level of variation is quite diverse intra-regions. Except for Oceania, which only has two countries in the analysis (Australia and New Zealand), Asia in the innovation input score and Europe in the output index have the highest standard deviation, reflected by the box's interquartile range. On the other end, African nations have less uneven innovation structure and performance patterns, which indicates that under average GII indexes, the spread would be more homogenous across the continent. It is worth mentioning that, in all three indexes, the means variations are statistically significant after running the Anova tests.

On the structure side, comparing the indexes scores also helps to understand the asymmetric patterns among regions. The five pillars of the input GII sub-index, which are critical components of the NIS, are constantly affected by the public policies at different levels. The radar chart (figure 6) displays each pillar means, which compares all five continents in a multidimensional perspective. The first impression from the graphs is that heterogeneity is the rule in the regions and among the indexes. The Anova tests demonstrated that, in all five input pillars, the average variations are statistically significant.

FIGURE 6
GII input indexes' pillars, by continent (2013-2020)



Source: GII.
Author's elaboration.

The institutional dimension attempts to reflect a comprehensive portrait of the countries' political economy' framework, including political, regulatory and, business environments. As expected, Oceania (85) and Europe (76) are top-ranked, while Africa (53) has the ranks the poorest. The American (58) and Asian (60) nations are in intermediary positions. Still, unevenness inside these continents is the highest, with the standard deviation of 15, which is not a surprise, considering the well-known historical instability in most of the political systems in these two regions.

Despite the complexity of this institutional arrangement, it seems that governments aiming to improve the NIS must develop and implement long-term policies and rules to provide friendly environments for investment and entrepreneurship. In this sense, this non-trivial path should focus on a stable political atmosphere and quality in policymaking and public services. Moreover, the usual recommendations for the development of the private sector, in regulatory and business affairs, rely on formulating and implementing policies that respect the rule of law (contract enforcement, property rights, the police, and the courts) and ease of starting a business and for resolving insolvency, among other initiatives.

The HC&R pillar reflects the level and standard of education, tertiary education and R&D in the nations, a key determinant of the economy's innovative capacity. It is also a dimension affected by the public sector interventions because education is predominately a state function. And science, technology, and innovation (ST&I) are sometimes considered risky investments for private entrepreneurship. Externalities and social returns are high and strategic for long-term development in these areas, which justifies the state's presence as a protagonist player (Lundvall, 2010; Reynolds, Schneider and Zylberberg, 2019). As the last pillar, the rank remains in the same order and with a significant gap among regions. Americas (27) to Oceania (54) is double the first in the averages of the HC&R scores. It is also worth noting the diversity of the indexes' patterns even in the same continents, especially in Asia.

Regarding elementary and secondary education achievements, measured by expenditure and school life expectancy, surprisingly, the differences among countries are not so high. Despite the increasing level of priority given to primary education, it is not observed at the college level. It is well-known that higher education institutions provide qualified professionals and researchers to the business sector and produce research results employed in their innovation process. In this sense, it is worrisome how the scores are low in the continents with the poorest performance in this dimension.

In short, governments must build cohesive policies and budgeting prioritization, considering the close correlation between education and research for enabling an environment for knowledge production, technology transfer, and innovation. As a result, the quality and level of the pillar's three dimensions play a central role for economies to move up the value chain beyond simple production processes and products.

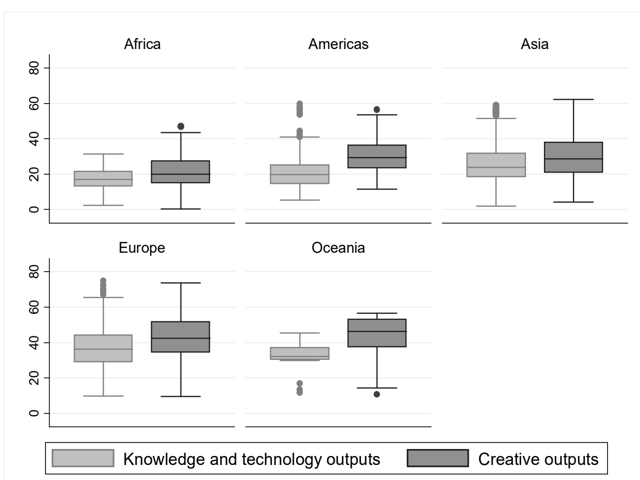
The infrastructure pillar involves ICTs, general (communication, transport, and energy), and ecofriendly environmental protection typically associated with increased productivity and efficiency, lower transaction costs, better access to markets, and consequence, sustainable growth. Once again, the regions' order in the rank is the same as Africa (28) in the worst position, on the other extreme, Oceania (53) and Europe (51) have not only the best indexes, but also proportionally less unevenness among their countries.

On the other hand, the market sophistication reflects a variety of dimensions that are to some extent less dependent on public sector intervention, such as investment environment, competition, and market scale. In sum, they represent complementary factors needed for innovation systems to raise funds and prosper. Based on the score's means, the economies positions are similar to the other pillars, but a highlight for the proximity between Europe (52), Asia (50) and Americas (47) with 20% of variation inside these regions.

Finally, another pillar less influenced by the government is business sophistication, which consists of how the private sector uses the human capital (knowledge workers and absorption) and the level of partnerships between public/private/academic. They are considered components of the NIS to promote business productivity and competitiveness by the employment of highly qualified professionals and technicians. It is worth noting how far the continents mainly composed by underdeveloped nations are from Oceania and Europe regarding the indexes.

On the performance end, the paper follows a similar logic to explore similarities and differences among continents. Besides the outputs' scores, the study also adds a discussion regarding its heterogeneity, both aspects depicted in the box plot below (figure 7) regarding the pillars KTOs and COs. In both cases, after running the Anova tests, the average variations are statistically significant. Moreover, overall, the output scores' ranks repeat the patterns observed in the input indexes.

FIGURE 7
GII output indexes' pillars, by continent (2013-2020)



Source: GII.
Author's elaboration.

The KTO pillar reflects the nation's achievement inventions and innovations by knowledge creation, impact, and diffusion activities. The distance between the Asian economies (26) is ever greater than Africa (17) and Americas (21) compared to ones noted in the input dimension. The former also has the highest disparity among its countries' performance. Europe has the second-highest standard deviation, but in this case, it leads the rank with a considerable range compared to all other continents, including Oceania (37 to 31).

Another performance pillar involves the capacity of the innovation system to be creative, including the provision of intangible assets, creative goods and services and, online creativity. The distances in the CO pillar index from Europe and Oceania to the rest are quite similar as in the previous output. The main difference comes from the better performance of America compared to Asia. Regarding heterogeneity, the CO's indexes present a much higher standard deviation in all continents than in the KTO pillar, which may reflect the distribution of science and technology (S&T) innovation clusters around the world. The top 100 clusters are concentrated in only 26 countries and the majority of them (over 70%) are in high-income economies. Except for China, which has seventeen S&T leading clusters, the emerging countries are represented only by Brazil, India, Iran, Turkey, and Russia, all of which have only eight innovation clusters (Dutta, Lanvin e Wunsch-Vincent, 2020).

4.3 A tentative typology for National Innovation Systems

The previous analyses presented the correlation between countries' innovation system inputs and outputs and economic prosperity and the evident gaps among continents in innovation structure and performance. In both cases, the empirical evidence demonstrates that heterogeneity among the economies is the rule, not the exception. However, these two aggregation strategies do not precisely describe how diverse the NIS are worldwide. First, the research looks for clusters using each country's average of the seven pillars scores of the GII index from 2013 to 2020. Table 1 displays the descriptive statistics of each variable.

TABLE 1
Descriptive statistics for cluster variables (2013-2020)

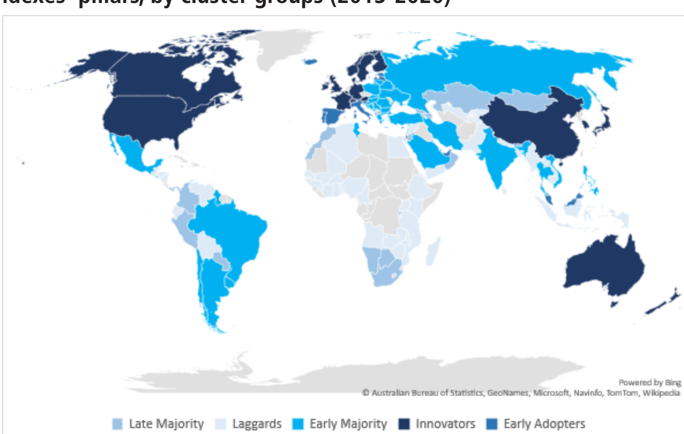
	N	Minimum	Maximum	Mean	Standard deviation
X_1 Institutions	148	18,7	94,3	62,2	15,7
X_2 Human capital and research	148	4,5	65,5	31,4	14,6
X_3 Infrastructure	148	12,7	66,1	39,8	13,3
X_4 Market sophistication	148	29,1	84,5	47,2	10,6
X_5 Business sophistication	148	10,1	64,2	33,4	11,3
X_6 Knowledge and technology outputs	148	2,5	67,7	25,9	12,6
X_7 Creative outputs	148	2,3	63,5	30,9	12,5

Source: GII.
Author's elaboration.

The paper employs the agglomerative hierarchical clustering methods, which begin with each observation being considered a separate group (*N* groups each of size 1). The closest two groups are combined (*N* – 1 group, one of size two and the rest of size 1), and this process continues until all observations belong to the same group, then, the process creates a hierarchy of clusters (Hair et al., 2006). Therefore, Ward's linkage clustering, a method that the similarity between two clusters is not a single measure of similarity but rather the sum of squares within the clusters summed over all variables, is employed. Considering that all seven variables are metric, squared Euclidean distance was chosen as the similarity measure. As a result, two stopping rules were used, the Calinski and Harabasz pseudo-F index and the Duda-Hart Je(2)/Je(1) index, that indicated the five-group solution as the most distinct from this hierarchical cluster analysis (Duda, Hart and Stork, 2001).

However, the cluster analysis results reinforce the heterogeneity rule detected in all seven dimensions with different patterns. To help the approach, an analogy well-known in the innovation literature is borrowed to name each group. Drawing from the Rogers (2003) seminal classification of innovation adopters, the paper adapts it to rank the types of country originated from the cluster analysis of their innovative structure and performance. It is worth mentioning that this is just an illustrative exercise to support the approach. The purpose is not to systematically compare these different observations but to show how the analyzed dimensions of the economies can also highlight a degree of stratification. In this sense, the five groups are ranked as follows: *innovators, early adopters, early majority*, *late majority*, and *laggards*. The figure 8 displays how the tentative typology is distributed around the globe.

FIGURE 8
GII indexes' pillars, by cluster groups (2013-2020)



Source: GII.
Author's elaboration.
Obs.: The countries in grey on the map are not included in the GII database.

The typology can be summarized as follows.

1) Laggards: the largest type of innovative economies are composed of 47 countries from Africa, Asia, and Latin America, but one common feature: low or lower-middle-income. These innovation national systems can be considered the most immature in the world (Lundvall et al., 2009), which may be a consequence not only of the notorious instability of their politics and the rule of law but also due to the magnitude of the market failures (Cirera and Maloney, 2017) and the characteristics of their economic production, mainly, agricultural focus with low added value.

2) Late majority: this group has twenty-nine nations also spread around the globe, including two Europeans (Albania and North Macedonia). They are primarily middle-income countries with low diversification and complexity in their economic production. In terms of innovation inputs, they share much higher scores in institutions, infrastructure and market sophistication than the laggards, whereas the outputs are very modest regarding human and technology capabilities.

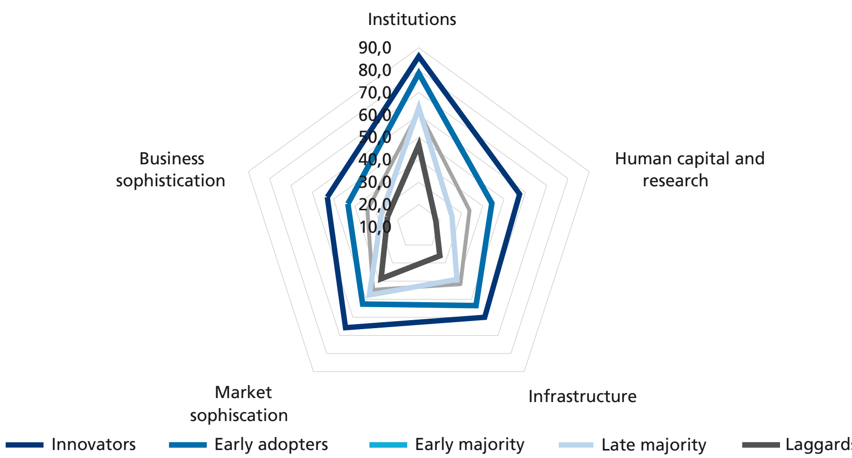
3) Early majority: the third type of innovation system is composed of 36 nations from middle to upper-middle-income countries. The group includes the greatest economies globally, such as Russia, Brazil, Mexico, and others that are part of the selected group, the Organisation for Economic Co-operation and Development (OECD). They have GII scores a little above average, which reflects a more complex and diversified economy than the previous two groups. Nonetheless, these nations continue to struggle with technological processes that keep almost all of them in the middle-income growth trap (Agénor, Canuto and Jelenic, 2012).

4) Early adopters: the most reduced type of innovation system has 13 high-income members, especially from the Eastern Europe and the Mediterranean regions, and members of OECD. In general, their innovation structure and performance, measured by the GII indexes, enable them to be considered prosperous economies. If not leaders in the field, at least they have mature NIS (Lundvall et al., 2009). Outside Europe, two countries are positive surprises: Malaysia and the United Arab Emirates. The former has been sophisticating its economic capabilities following the example of other prosperous eastern Asian countries, while the Arabic nation is paving a different way from its neighbors by investing in innovation to overcome the restricted oil-dependent economy.

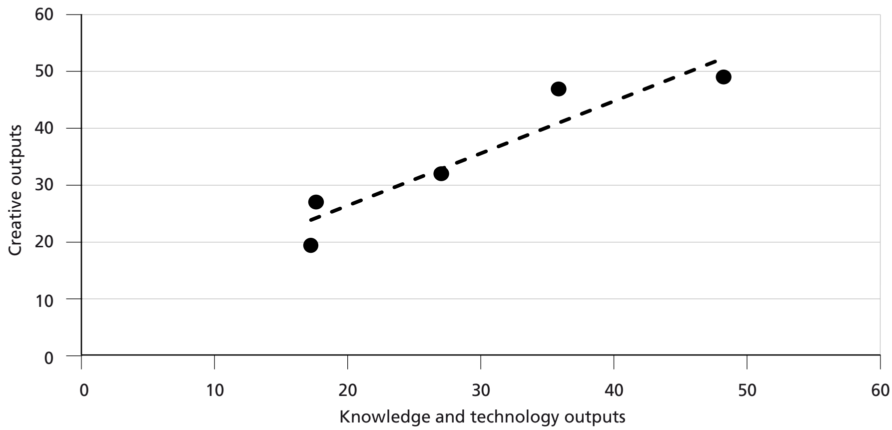
5) Innovators: the top-ranked type of innovation system has 22 economies distributed in four continents. The group, composed of developed anglo countries, Western Europe and Eastern Asia, leads all seven GII indexes, impacting not only their wealth but also the complexity and specialized level of their economic capabilities and production. These NIS aggregate high-income nations that have strategically prioritized this policy agenda and the Asian Tigers (South Korea, Taiwan, Singapore and Hong Kong), which went through the desired technological catch-up process in the last four decades. Once again, China stands out because it is the only upper-middle-income country in this cluster and has improved its rank, for instance, in the output dimension, from 35th to 14th in just eight years. Moreover, this outstanding performance tends to improve, considering that the Asian nation has 17 of the 100 clusters S&T intensity, the number behind only from the United States of America (25 clusters).

The two charts below (figure 9) display the inputs and outputs variables, grouped by each NIS type.

FIGURE 9
GII indexes' pillars, by cluster groups (2013-2020)
9A – GII inputs of cluster groups



9B – GII outputs of cluster groups



Source: GII.
Author's elaboration.

The radar chart shows the average inputs indexes, previously discussed in figure 6, now organized by the five cluster groups. First, the distance from the countries best ranked (innovators and early adopters) to the rest is much higher than when aggregated by continents. The means in almost all dimensions from *early majority* and *late majority* (except for HC&R) is quite similar to the Americas and Asia. In contrast, the laggards countries have indexes averages close to the ones identified in Africa. As expected, the groups have more homogeneous scores, depicted by lower standard deviation. In addition, the clustering allows one to identify similarities, especially among innovators, that dilated all their inputs indexes means and demonstrated how advanced these countries are in terms of innovation structure.

In the same direction, the scatter plot above shows the distribution of the output indexes means of the five types of countries. The laggards have the worst outputs performance. However, the distance from the late majority group is very short in the KTO results. The early majority appears precisely between them and the early adopters. The latter shows a good performance in both dimensions, but they are still far from the top nations' outputs. Finally, the innovators stand out, reflecting the reduced but highly productive set of countries leading the innovation worldwide. Another interesting aspect of the graph is the tendency line (dashed), which indicates how correlated these two results variables are. In general, around 90% of the performance by the countries in the KTO is followed by similar achievement regarding the COs.

5 FINAL REMARKS

As the paper title states, heterogeneity is the rule, not the exception, regarding the NIS. It is not a novelty, but it still lacks empirical knowledge on how this uneven pattern occurs. In this context, comparing countries' innovation structure and performance worldwide under a different perspective make the inquiry's findings so original and relevant.

These exploratory analyses are essential for two main reasons. First, the fact that innovation growth is driving nations' economic progress and competitiveness. Secondly, the increasing consensus that a thriving innovation system depends on a comprehensive and complementary political economy approach, including institutions, knowledge, HC&R, financial resources, and infrastructure, among others.

In all paper's analyzes, the inequality among economies was quite evident. First, comparing countries' income levels and their innovation indexes, the results reinforce that the higher the economic development, the better the innovative capacity, as expected. However, the correlations between these two aspects were not precise since some rich nations do not have a mature NIS, as in the Middle East cases. In contrast, others with intermediate income levels show a high standard in innovation, such as China. Besides, the analysis also demonstrated that the GDP is more correlated with the nations' performance indexes than with innovation structure.

In the regional threshold, the findings highlighted that Europe and Oceania have the most sophisticated innovation systems, whereas Africa, on the other hand, occupied the lowest rank in the GII. The paper also mapped the uneven patterns inside the continents, evident in all GII pillars of innovation inputs and outputs, especially in the Americas and Asia.

The third approach added more complexification to the analysis by proposing a unique taxonomy of NIS from clustering with the seven GII sub-pillars indexes. The results generated five types of NIS that aggregated a high level of similarities inside each group of countries and showed the degree of distance among them. Then, the cluster analysis displayed an even more accurate description of how countries are in terms of innovation inputs and outputs than the income or continent cohorts. The main message is that the world *innovators*, followed by *early adopters*, have built NIS with similar features that cross the regional borders and encompass all the complementary dimensions of the mature innovation systems depicted by the literature (Lundvall et al., 2009; Cirera and Maloney, 2017; Fagerberg, 2017).

In short, the inquiry brought some interesting findings, especially because it provided different views of the NIS disparities around the world based on the employment of complementary methodological strategies. Nevertheless, they must be considered with caution because of the well-known limitations of comparison on comprehensive surveys used by the GII, such as the World Banks's "good governance" indexes (Andrews, 2008) and the *Doing Business*, which was recently discontinued due to a variety of data irregularities in recent editions.[4]

In this sense, for future research agendas, another approach to advance in innovation systems research is to focus on qualitative analysis to comparatively investigate the institutional features and constraints embedded in pivotal countries' innovation dimensions, for instance, by employing qualitative comparative analysis (QCA). The second alternative is to discuss empirical insights of drivers and barriers for the continuing and dynamic innovation growth. This strategy may involve in-depth case studies, i.e., an up-close and detailed examination of how the successful innovation policies are designed and implemented. In this sense, the analysis must focus on governmental capabilities, organizations, and initiatives to deal with different issues, such as the range of the state roles, the balance between coordination versus fragmentation, the degree of public-private partnership, the effectiveness of ST&I strategies, and national plans.

Nonetheless, the progress in exploring how innovation systems are structured and actually operate is undoubtedly a prominent subject for the innovation and development field of study. It is even more important because the concepts are still evolving. Simultaneously, there is an increasing demand for evidence-based knowledge for better NIS in different political, economic, and administrative realities in which innovation policies are formulated and implemented worldwide.

Therefore, it is also crucial to continue the efforts to understand the cases of nations that have improved their high level of innovation capacity, those that experienced successful catch-up processes, and the developing countries which are still struggling to increase innovation to overcome their lagging productivity. Additionally, these studies may also offer new insights regarding how they face the occurrence of a phenomenon similar to "great divergence", i.e. when few exceptions of rich nations continue to pull ahead.

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