ECONOMICS

RECEIVED:
10 September 2024
ACCEPTED:
11 November 2024
RELEASED:
20 December 2024

UDC 330.341.1:005.591.6(100)

DOI 10.26661/2522-1566/2024-4/30-01

LINKING NATIONAL INNOVATION SYSTEMS AND INNOVATION CAPACITY

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Abstract. National Innovation Systems (NIS) are fundamental in shaping a country's innovation capacity, influencing economic diversification and sustainable growth. The **purpose** of this study is to examine the role of well-structured and functional NIS in fostering innovation capacity across diverse contexts, including resource-rich countries, leading innovative nations, and developing regions. This research employs a comparative analysis **methodology**, drawing on data from global innovation indices, case studies, and academic literature to evaluate key metrics such as R&D investment, patent activity, university-industry collaboration, and public-private partnerships. The **findings** reveal significant disparities in innovation performance, with resource-rich countries often constrained by systemic challenges like the "resource curse," while nations such as Norway and Canada illustrate how strategic management of natural wealth drives sustainable innovation. Similarly, developing regions face barriers including weak institutional frameworks and limited funding, yet exhibit potential for progress through targeted reforms.
The findings underline the importance of robust NIS structures, emphasizing the need for greater investment in R&D, stronger university-industry collaboration, and enhanced public-private partnerships as crucial enablers of innovation capacity. Practical and policy implications are needed in offering actionable strategies for overcoming systemic challenges, improving innovation ecosystems, and achieving economic resilience.

Keywords: National innovation systems (NIS), innovation capacity, innovation ecosystems, research and development (R&D).
Jel Classification: O31, O32, R11, O57.

INTRODUCTION

The theory of comparative advantage, formulated by David Ricardo, posits that a nation endowed with abundant natural resources has an economic advantage over others. This advantage arises from specialization in the exploitation of specific resources and subsequent trade, which theoretically leads to an increase in national wealth, all else being equal. According to Ricardo, a resource-rich nation can maximize productivity by focusing on the exploitation of these resources while importing goods for which it is less competitive (Ricardo, 1817).

However, this optimistic view is not consistently observed in contemporary contexts. Many resource-rich economies face a complex phenomenon known as the "resource paradox" or the "resource curse" (Auty, 2002). This paradox describes a situation in which countries with abundant

natural resources often experience slower economic growth compared to resource-poor nations. Causes include over-reliance on resource exports, price volatility in commodity markets, weak infrastructures, malfunctioning systems, and poor governance of resource revenues.

Many resource-rich countries frequently struggle to diversify their economies and establish robust innovation systems. This situation contrasts sharply with nations such as Norway and Canada, which have successfully leveraged their natural wealth to invest in innovative and sustainable sectors (Mehlum et al., 2006).

Moreover, modern theories on national innovation systems, such as those proposed by Lundval (1992), suggest that natural resource wealth does not inherently guarantee increased innovation capacity. Innovation requires targeted investments in research and development (R&D), effective collaboration between public and private sectors, and an advanced educational and technological ecosystem. Consequently, the relationship between natural resources and national prosperity must be contextualized within a broader framework that includes institutional, economic, and social factors.

NIS are defined as the network of institutions, policies, and interactions that facilitate the flow of knowledge and technology among various actors, including government, industry, and academia. The concept of innovation capacity refers to a nation's ability to produce and commercialize innovative technologies effectively. Understanding the relationship between NIS and innovation capacity is crucial for policymakers aiming to enhance national competitiveness and economic growth.

In this context, it is crucial to examine why some nations succeed in transforming their natural resource wealth into a driver of innovation and economic diversification, while others remain trapped in cycles of dependency and stagnation. A deeper analysis of regional and national cases can provide valuable insights into the conditions necessary to overcome the "resource curse" and promote sustainable economic and technological development.

In the contemporary global economy, innovation has become a critical determinant of national competitiveness, economic growth, and social well-being. A country’s ability to innovate-its innovation capacity-depends not only on its investment in research and development (R&D) but also on the effective functioning of its National Innovation System (NIS). The concept of NIS refers to the network of institutions, policies, and actors that contribute to the generation, diffusion, and application of new knowledge, technologies, and processes within a country (Lundvall, 1992); (Nelson, 1993).

The relationship between NIS and innovation capacity has become a key area of research due to the growing recognition that innovation does not occur in isolation but is instead the product of systemic interactions among various actors, including the government, universities, research institutions, and private enterprises (Etzkowitz & Leydesdorff, 2000). NISs are typically shaped by government policies, technological infrastructure, education systems, and public-private collaborations. Regions and countries that have robust NISs are better equipped to respond to global challenges and maintain their technological edge in a rapidly changing world.

This paper aims to explore how different national innovation systems impact innovation capacity, highlighting key theoretical frameworks and regional differences, the research highlights how institutional structures, collaborative networks, and strategic investments mainly in R&D influence innovation outcomes. It also underscores the disparities between countries that have successfully converted resource wealth into innovation-driven growth, such as Norway and Canada, and those that remain dependent on resource extraction. The findings provide critical insights for policymakers seeking to enhance national innovation capacity and foster economic resilience.

To frame this analysis, the study applies theoretical models such as the NIS framework, which emphasizes the interactions between government, academia, and industry in driving innovation. Supplementary models, including the Triple Helix and innovation cluster theories, are also utilized to contextualize the influence of collaboration and institutional dynamics on innovation outcomes. The research integrates secondary data from reputable sources such as the UNESCO Institute for

Statistics, the World Bank Databank, and global innovation indices. Empirical case studies and academic literature provide qualitative insights to complement the quantitative evaluation of innovation performance indicators.

This methodology, combining theoretical analysis with empirical data, ensures a comprehensive understanding of how National Innovation Systems contribute to innovation capacity. It provides a nuanced perspective on the challenges and opportunities facing countries and regions as they strive to enhance their innovation ecosystems and achieve long-term economic and technological progress.

LITERATURE REVIEW

National Innovation Systems have emerged as a crucial concept for understanding how countries foster innovation and technological advancement. The notion, first popularized by Freeman in the 1980s, emphasizes the interactions among various actors, including government, industry, and academia, that contribute to a nation's innovative capacity (Sharif, 2006). This literature review aims to synthesize existing research on NIS, focusing on its components, dynamics, and implications for innovation capacity.

It is a framework that emphasizes the interactions and linkages between various actors-such as government agencies, research institutions, universities, and private firms-that collectively contribute to a nation's innovation process (Lundvall, 1992) (Lundvall, 2016). NIS is seen as a complex and dynamic system where the flow of knowledge and resources between these entities shapes the development and diffusion of innovations.

The relationship between NIS and innovation capacity is a critical area of study that examines how the structural and functional elements of a nation’s innovation ecosystem influence its ability to generate and implement innovations. National innovation systems encompass the institutions, policies, and interactions that facilitate the flow of knowledge and technology among various actors, including government, industry, and academia. This interplay is essential for fostering an environment conducive to innovation, which in turn enhances a country's innovation capacity.

National innovation capacity refers to a country's ability to produce and commercialize innovative technologies effectively; it is influenced by several factors, including the quality of research and development (R&D) activities, the level of human capital, and the robustness of information and communication technology (ICT) infrastructure Karahan (2017). The NIS framework provides a comprehensive understanding of how these elements interact to shape innovation outcomes. For instance, Furman et al. emphasize that national innovative capacity is determined by the strength of a nation's innovation infrastructure and the relationships within its industrial clusters (Furman et al., 2000). This highlights the importance of collaborative networks and institutional support in enhancing innovation capacity.

Moreover, the dynamics of NIS are characterized by the coevolution of innovative capability and absorptive capacity, as demonstrated by Castellacci and Natera. Their research indicates that the interplay between these two dimensions significantly impacts the overall innovation performance of a nation (Castellacci & Natera, 2013). Absorptive capacity, which refers to the ability of organizations to recognize, assimilate, and apply external knowledge, is crucial for leveraging innovations generated within the NIS. This relationship underscores the necessity of fostering both innovative and absorptive capacities to achieve sustainable economic growth and competitiveness.

The NIS concept has evolved significantly since its inception. Sharif provides a comprehensive analysis of how the formal body of NIS knowledge has developed, examining its codification and dissemination within the academic community (Sharif, 2006). The framework has been instrumental in understanding the importance of institutions, policies, and cultural factors for the innovation outcomes.

The effectiveness of a national innovation system is also contingent upon the interactions among its various components. As noted by Perez-Astray and Calvo-Babio, the capacity for innovation is not solely dependent on quantitative R&D efforts but also on the creation of externalities through effective collaboration among stakeholders, including universities, industry, and government (Perez-Astray & Calvo-Babio, 2011). This collaborative approach facilitates knowledge transfer and enhances the innovation ecosystem, thereby improving the overall innovation capacity of the nation.

Innovation does not occur in isolation but is the result of systemic interactions among various actors. Successful NIS often feature strong collaboration between universities, industry, and government-a concept central to the Triple Helix Model (Etzkowitz & Leydesdorff, 2000). Interface organizations, as highlighted in one of the references, play a critical role in facilitating these collaborations by acting as bridges that transfer knowledge from academia to industry. Such entities enable countries to maximize the impact of their R&D investments.

Geographical and institutional clusters also amplify innovation capacity. Malaysia's Multimedia Super Corridor, as noted in the dataset, is a prime example of a well-functioning innovation cluster. Concentrating research, industry, and infrastructure in one region fosters knowledge spillovers, enhances institutional relationships, and drives innovation outputs. These lessons are crucial for nations seeking to replicate similar success.

Furthermore, the impact of cultural and institutional factors on innovation capacity cannot be overlooked. The socio-cultural context shapes the attitudes and behaviors of individuals and organizations towards innovation. For instance, Lažnjak discusses how national innovation culture influences the effectiveness of innovation policies and the overall innovative capacity of a nation. This cultural dimension is critical in understanding why certain countries excel in innovation while others lag behind, as it affects the willingness to adopt new technologies and engage in collaborative innovation efforts.

For many developing nations, the path to building robust innovation systems is fraught with challenges. Resource-rich countries like Algeria and Venezuela often fall victim to the resource curse, where overreliance on natural resources stifles diversification and innovation (Mehlum et al., 2006). Limited R&D spending, weak public-private partnerships and inconsistent policies further constrain their ability to compete on a global scale.

NIS encompasses several key components, including 1) Institutions: The rules, regulations, and norms that govern interactions among actors within the innovation ecosystem. Strong institutions are essential for fostering an environment conducive to innovation (Tsai, 2001). 2) Actors: Various stakeholders, including government agencies, research institutions, and private enterprises, play critical roles in the innovation process. Their interactions facilitate knowledge transfer and collaboration (Haghi, 2013). And 3) Infrastructure: The physical and technological infrastructure that supports innovation activities, such as research facilities and ICT networks, is vital for enhancing a nation's innovative capacity (Chang & Fan, 2017).

Karahan's empirical investigation of European countries reveals a strong relationship between national innovative capability and performance indicators, suggesting that countries with robust NIS tend to perform better in innovation metrics (Karahan, 2017). Similarly, Cvetanović et al. argue that national innovation capacity is a key determinant of economic progress, emphasizing the importance of measuring this capacity to understand the dynamics of innovation within economies (Cvetanović et al., 2021).

A comparative analysis of innovation systems across different countries can provide insights into best practices. For instance, Andrijauskienė and Dumčiuvienė's study on inward foreign direct investment (FDI) demonstrates that FDI can enhance national innovative capacity by facilitating knowledge transfer and boosting employment in knowledge-intensive sectors (Andrijauskienė & Dumčiuvienė, 2019).

We may say that the relationship between national innovation systems and innovation capacity is multifaceted and influenced by a variety of factors, including institutional frameworks,

collaborative networks, absorptive capacity, and cultural contexts. A robust NIS enhances a country's ability to innovate by fostering an environment that encourages knowledge sharing and collaboration among various stakeholders. As nations strive to improve their innovation capacities, understanding and optimizing the dynamics of their national innovation systems will be essential for achieving sustainable economic growth and competitiveness.

Domazet et al. argue that national innovation capacity is a driving force behind economic prosperity, highlighting the importance of measuring this capacity to understand the dynamics of innovation within economies (Domazet et al., 2022). Furthermore, the findings of Karahan suggest that dimensions such as R&D activities and human capital are critical for enhancing national innovation capacity (Karahan, 2017).

A well-functioning NIS requires a favorable environment that supports the creation, diffusion, and commercialization of new ideas and products; we may resume the key components of NIS in the following ones:

1. Research and Development (R&D) Infrastructure: Research institutions and universities are essential actors in the innovation process. These institutions generate new knowledge, conduct fundamental and applied research, and collaborate with firms to bring innovations to market.

2. Government Policies: Public policies, including those related to R&D funding, intellectual property rights, and tax incentives, play a critical role in shaping the innovation ecosystem.

3. Human Capital: The availability of a skilled workforce-produced by education systems-acts as a key driver for innovation, as individuals with technical expertise are necessary to convert new knowledge into innovative products and services (R. Cohen, 1987).

4. Public-Private Partnerships: Collaboration between the public and private sectors is essential for the successful commercialization of innovations, as firms can often bring academic research into practical applications.

Meanwhile; innovation capacity refers to the ability of a country to produce and utilize new knowledge, technologies, and innovations. It involves not only the ability to generate new ideas but also the capacity to absorb external knowledge and transform it into useful innovations (W. Cohen & Levinthal, 1990). Zhan et al. demonstrate that structural innovation input positively correlates with innovation output, affirming the NIS perspective (Zhan et al., 2015). This relationship underscores the importance of investing in institutional frameworks and collaborative networks to boost innovation capacity, which is often assessed through several indicators, such as:

1. R&D Investments: The amount of financial resources allocated to research and development activities, both by the public and private sectors.

2. Technological Outputs: Indicators such as patents, new products, and process innovations, which demonstrate the tangible results of an innovation system.

3. Knowledge Absorption: The ability of firms, universities, and other institutions to incorporate external knowledge into their operations, enhancing their capacity to innovate.

We may also adopt the following table from Lundvall (2016) to describe the main components of a National Innovation system (NIS)/

Innovation capacity also depends on institutional factors such as governance, regulatory frameworks, and economic stability, which determine how efficiently an innovation system operates. Several theoretical perspectives help explain the relationship between NIS and innovation capacity. These models emphasize the systemic nature of innovation and the importance of knowledge flows, institutional structures, and government policies.

The System of Innovation Theory (Lundvall, 1992; Nelson, 1993) posits that innovation is the result of interactions between various actors in the national system, such as universities, research institutions, firms, and the government. The system is characterized by continuous learning processes where knowledge is generated, shared, and applied. In this framework, a country's innovation capacity is enhanced when actors interact effectively and engage in knowledge exchange and collaboration.

Table 1

Key Components of a National Innovation System (NIS)

Component	Description
Internal Firm Dynamics	Firms play a key role in adopting new technologies. Understanding how internal departments, such as sales, research and development (R&D), and production, collaborate is essential for fostering innovation. This research highlights the importance of internal processes within SMEs in driving the successful implementation of Fourth Industrial Revolution (4IR) technologies.
Collaboration Between Firms	Inter-firm relationships drive innovation by fostering knowledge exchange and collaboration. Key mechanisms include partnerships within industrial clusters, technical collaborations, and user-producer interactions. This study examines how SMEs leverage external networks and partnerships to facilitate the adoption technologies.
Public Sector's Role	The public sector including governments is essential for the innovation ecosystem by implementing policies, regulations, funding initiatives, and setting industry standards. These actions significantly influence the direction and pace of innovation.
Financial Systems and Support	Providing the funding needed to support technological advancements. Their role links the financial system to a nation's overall innovation capacity. This research explores various funding mechanisms, such as venture capital and public financing, and how they contribute to SMEs' adoption of technologies.
Research & Development Systems	Research and development (R&D) systems are fundamental to fostering innovation, as they involve the necessary resources, expertise, and organizational structures. This study analyzes R&D systems in both developed and developing nations to understand their impact on accelerating the adoption of technologies.

Source: Adapted from Lundvall (2016).

The Triple Helix model emphasizes the roles of government, industry, and universities in creating a conducive environment for innovation. According to this theory, innovation capacity is enhanced when these three entities collaborate to support technological development, knowledge creation, and commercialization. This model underscores the importance of public-private partnerships in fostering innovation and increasing a nation's innovation capacity. (Etzkowitz & Leydesdorff, 2000)

According to The Absorptive Capacity Theory, a high absorptive capacity enables countries to innovate by integrating external technological advancements into their own systems (Cohen & Levinthal, 1990). Innovation capacity is therefore linked not only to the ability to generate knowledge internally but also to the ability to absorb and apply knowledge from other nations or regions. Research by Tsai highlights that high absorptive capacity is associated with improved innovation performance (Tsai, 2001). This finding suggests that organizations with strong absorptive capacity can leverage external knowledge more effectively, leading to enhanced innovative outcomes.

Finally, The Innovation Systems and Globalization framework proposed by Archibugi & Michie (1997) suggests that national innovation systems are increasingly shaped by global flows of knowledge and technology. In a globalized world, no country's innovation system is completely isolated. Instead, countries depend on international knowledge networks, foreign direct investment, and cross-border collaborations to enhance their innovation capacity. This view highlights the role of globalization in influencing national systems of innovation. (Archibugi & Michie, 1997)

Factors Influencing Innovation Capacity

The literature in the domain of innovation and national innovation systems highlight different factors and actors influencing the innovation capacity of an economy, we limit them to the following ones:

1. Institutional Frameworks

The institutional context plays a significant role in shaping a nation's innovation capacity. Adeoti emphasizes that technological innovation is crucial for firm competitiveness and, subsequently, for the competitiveness of the national economy(Adeoti, 2002). Strong institutions that support innovation through policies and funding can significantly enhance national innovative capacity.

2. Collaborative Networks

Collaboration among various actors within the NIS is essential for fostering innovation. Halkos and Skouloudis argue that corporate social responsibility (CSR) can intersect with innovative capacity at a macro level, suggesting that enabling conditions for CSR can enhance innovation (Halkos & Skouloudis, 2018). This indicates that fostering relationships among businesses, government, and academia can lead to improved innovation outcomes. Pérez-Astray and Calvo-Babio emphasize that the capacity for innovation is not solely dependent on R&D efforts but also on the creation of externalities through effective collaboration among stakeholders (Perez-Astray & Calvo-Babio, 2011). This collaborative approach facilitates knowledge transfer and enhances the innovation ecosystem, thereby improving overall innovation capacity.

3. Absorptive Capacity

Absorptive capacity, defined as the ability of organizations to recognize, assimilate, and apply external knowledge, is crucial for leveraging innovations generated within the NIS. Castellacci and Natera highlight the coevolution of innovative capability and absorptive capacity, indicating that these dimensions significantly impact the overall innovation performance of a nation (Castellacci & Natera, 2013).

4. Cultural Context

Cultural factors also influence innovation capacity. Clark notes that in many developing countries, hierarchical social structures can impede the horizontal connectivity necessary for healthy innovation systems (Clark, 2002). Understanding the cultural context is essential for designing effective innovation policies that resonate with local practices and values.

RESULTS AND DISCUSSION

The performance of national innovation systems can be quantitatively assessed through various indices and frameworks. Park et al. propose eco-innovation indices that categorize countries into leaders, followers, and laggards based on their eco-innovation performance (Park et al., 2017). This classification allows policymakers to identify best practices and areas for improvement. Similarly, Stoian and Nica argue that the functionality of a country's governmental system is a critical determinant of its innovation success, suggesting that nations with robust governance structures tend to achieve better economic outcomes through innovation (Stoian & Nica, 2016).

The comparative analysis of NIS also reveals significant disparities in innovation efficiency among countries. For example, research by Alnafrah et al. on BRICS countries indicates that while Russia exhibits a strong innovation system, India lags behind, demonstrating the diverse structural characteristics and performance levels within the same group of emerging economies (Alnafrah et al., 2018). This finding underscores the importance of tailored policies that consider the unique contexts of each country.

Additionally, the role of technology and human capital in shaping national innovation systems cannot be overstated. Studies have shown that countries with higher levels of human capital and technological capabilities tend to perform better in innovation metrics (Aleknavičiūtė Rasa et al., 2016). For instance, Freitas discusses how the interaction between NIS and economic development is particularly evident in China, where strategic investments in human capital have propelled its innovation capabilities (Freitas, 2023). This relationship is further supported by the findings of Jankowska et al., who highlight the importance of institutional quality and governance in enhancing the efficiency of innovation systems in Poland and Bulgaria (Jankowska et al., 2017).

Furthermore, the integration of cross-border regional innovation systems (CBRIS) has emerged as a significant area of study, particularly in the context of globalization. Makkonen et al. argue that cross-border collaboration can enhance innovation by leveraging regional strengths and facilitating knowledge transfer (Makkonen et al., 2017). This perspective is crucial for understanding how innovation systems can evolve in a more interconnected world, where traditional national boundaries may no longer adequately capture the dynamics of innovation.

The relationship between National Innovation Systems (NIS) and innovation capacity in Africa is a complex interplay that significantly influences the continent's economic development and technological advancement. National Innovation Systems encompass the institutions, policies, and interactions that facilitate the generation, diffusion, and utilization of innovations within a country. In Africa, the development of NIS is crucial for enhancing innovation capacity, which is often hindered by systemic challenges such as inadequate infrastructure, limited access to funding, and a lack of skilled human resources (O. Toivanen & Cressy, 2002); (H. Toivanen & Ponomariov, 2011); (Oluwatobi et al., 2014).

One of the primary challenges facing African NIS is the fragmentation and weakness of existing innovation systems. Many African countries lack coherent innovation strategies, leading to disjointed efforts in fostering innovation (Gachie & Govender, 2017). This fragmentation is exacerbated by the historical context of resource nationalism and political instability, which can stifle collaborative efforts necessary for a robust NIS (Kahn, 2014). Moreover, the brain drain phenomenon, where skilled individuals migrate to more developed countries, further undermines the innovation capacity of African nations (H. Toivanen & Ponomariov, 2011). Addressing these issues requires a concerted effort to strengthen institutional frameworks and enhance government effectiveness, which have been shown to significantly impact innovation outcomes (Oluwatobi et al., 2014).

Furthermore, the role of education and training in building innovation capacity cannot be overstated. Programs aimed at developing agricultural education and training systems have demonstrated the potential to enhance innovation capacity in sub-Saharan Africa (Gill et al., 2016); (Spielman et al., 2008). By fostering a skilled workforce that is equipped to engage with and contribute to the NIS, these initiatives can help bridge the gap between research and practical application, thereby facilitating the translation of innovative ideas into tangible economic benefits (Manzini, 2015).

In addition, the integration of local and informal innovation systems into the broader NIS framework is essential for recognizing the diverse sources of innovation that exist within African economies. Local innovations often arise from grassroots initiatives that are well-suited to the specific needs and contexts of communities (Links et al., 2014). Therefore, policies that encourage the recognition and support of these local systems can enhance the overall innovation capacity of the national system.

Moreover, intellectual property rights (IPR) play a critical role in fostering innovation by providing the necessary legal framework to protect and incentivize inventors and entrepreneurs (Chen & Puttitanun, 2005). In many African countries, the lack of effective IPR systems can deter investment in innovation and limit the potential for domestic invention. Strengthening IPR frameworks can thus be a vital step in enhancing the innovation capacity of African nations.

In Sub-Saharan Africa, for example, systemic barriers such as inadequate infrastructure and brain drain hinder the development of effective NIS. Similarly, South Asia faces challenges in bridging the gap between academia and industry, with university-industry collaboration indexes remaining low relative to East Asia or North America. Addressing these gaps requires targeted investments in education, infrastructure, and policy reform to unlock these regions' full innovation potential.

The figure below presents a comparative analysis of NIS across major innovative countries. The comparison focuses on four key metrics: R&D Investment, Patents Filed, University-Industry Collaboration, and Public-Private Partnerships. These metrics highlight the strengths and

weaknesses of each country's innovation ecosystem and provide insights into their relative innovation capacity.

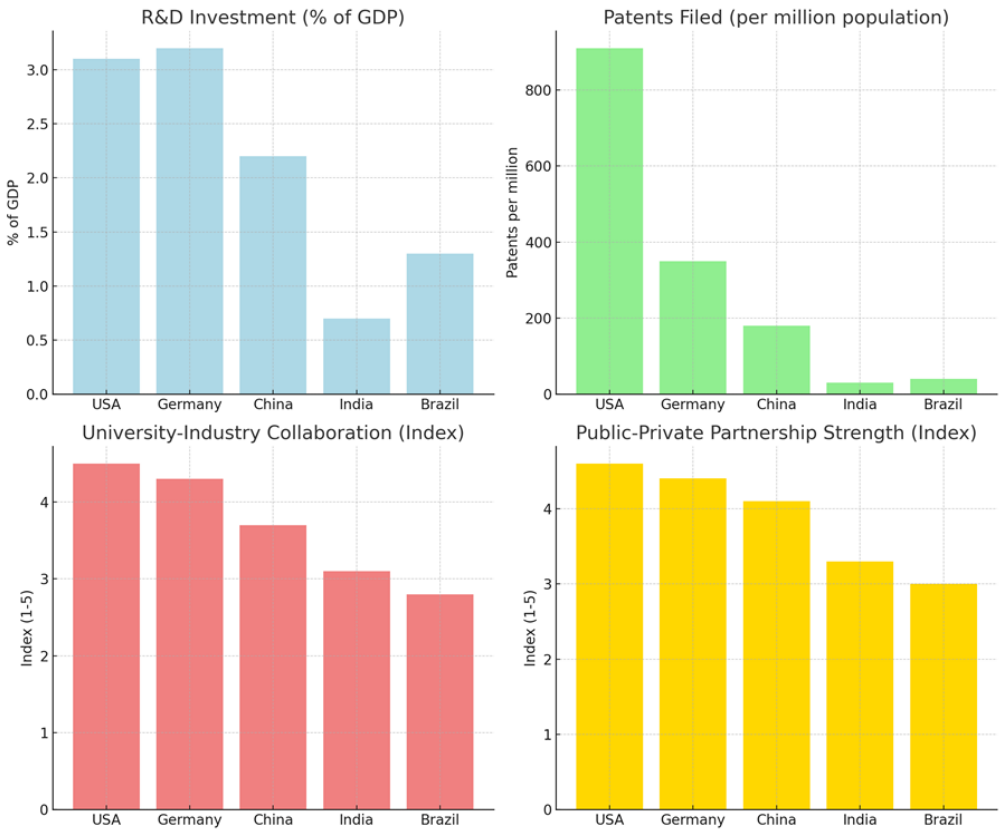

Fig. 1. NIS across major innovative countries
Adapted from (UNESCO Institute for Statistics, 2024) and (World Bank, 2024)

Innovation performance varies significantly across these countries, reflecting differences in investment, collaboration, and output. Research and Development (R&D) expenditure as a percentage of GDP serves as a key indicator of a nation's commitment to fostering innovation. Leading the charge are South Korea, with an impressive 4.8%, and Japan at 3.4%, exemplifying their focus on innovation-driven economies. These figures underscore a strategy heavily reliant on cutting-edge technologies and advanced industries. Meanwhile, nations like the USA and Germany also display strong ecosystems, with investments of approximately 3.1–3.2% of GDP. In contrast, India (0.7%) and the UK (1.7%) fall short, indicating constrained budgets and potentially limited technological advancements, particularly in sectors requiring significant capital.

Patent filings per capita reveal another dimension of innovation capacity. The USA stands out with 910 patents filed per million people, a testament to its vibrant technological ecosystem and a culture of entrepreneurship. Japan and South Korea follow closely, reflecting their sustained investment in R&D and robust intellectual property frameworks. Conversely, China and India lag significantly, with 180 and 30 patents per million, respectively. This gap highlights the challenges these nations face in translating research into commercialized innovations, which may be attributed to weaker institutional support or limited access to advanced infrastructure.

Collaboration between universities and industries plays a pivotal role in bridging the gap between theoretical research and practical application. South Korea excels in this area, scoring 4.6 on collaboration indices, reflecting its strong culture of applied research. The USA (4.5) and Germany (4.3) similarly maintain solid frameworks that foster partnerships between academia and industry. However, emerging economies like India (3.1) and China (3.7) demonstrate significant

room for growth. The absence of robust mechanisms for knowledge transfer in these countries often limits the scalability and applicability of research outcomes.

Public-private partnerships further amplify the effectiveness of innovation systems. South Korea and the USA lead once again, with scores of 4.7 and 4.6, respectively, showcasing highly integrated ecosystems where government policies align seamlessly with private sector objectives. Japan and Germany, scoring 4.5 and 4.4, maintain steady partnerships that bolster their innovation outputs. Meanwhile, India (3.3) and China (4.1) trail, suggesting a need for more coordinated efforts to align public funding with private-sector innovation.

From a broader perspective, these differences underscore the critical components that drive successful National Innovation Systems. Countries like South Korea, Japan, and the USA consistently outperform others due to their strategic investments in R&D, robust intellectual property outputs, and strong collaboration frameworks. These nations have institutionalized mechanisms to ensure that research translates into tangible innovations, contributing to their global leadership in advanced industries.

Emerging economies such as China and India, while showing potential, face structural and systemic challenges. Limited funding, weaker industry-academia linkages, and less integrated public-private partnerships hinder their ability to catch up with the global leaders. Closing these gaps requires policy interventions aimed at increasing R&D funding, improving intellectual property regimes, and fostering collaborative ecosystems. For India and China, enhancing university-industry linkages is particularly crucial to leverage their large pools of academic talent effectively. The comparative analysis highlights that national innovation performance is not merely a function of financial investment but also a reflection of how well institutions, industries, and governments collaborate. For lagging nations, a focused strategy on improving partnerships and fostering an innovation-friendly regulatory environment will be essential to achieving competitiveness in the global technology.

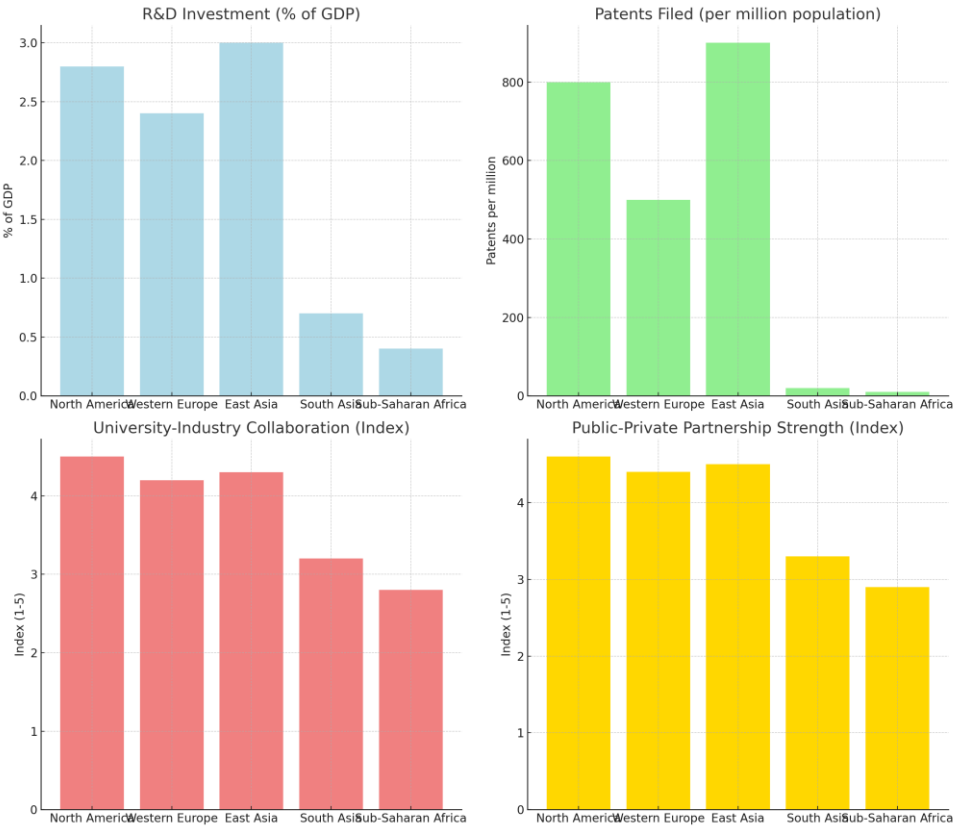

Fig.2. Innovation Systems Across Global Regions
Adapted from (UNESCO Institute for Statistics, 2024) and (World Bank, 2024)

We find that North America exemplifies a dynamic innovation system with strong private-sector engagement and a robust entrepreneurial culture. With R&D investment at 2.8% of GDP and 800 patents filed per million people, the region demonstrates a significant focus on technological advancement. High indices in university-industry collaboration (4.5) and public-private partnership strength (4.6) further solidify its leadership in translating research into impactful commercial applications. This synergy between academia, industry, and government is a hallmark of North America's innovation success.

While Western Europe stands out for its sustainability-focused innovation and solid public-private partnerships. Despite slightly lower R&D investment (2.4% of GDP) compared to North America, the region maintains a strong focus on environmental and societal challenges, embedding innovation into its broader policy agenda. A patent filing rate of 500 per million people reflects the region’s balanced approach to fostering both technological and social innovation. Collaborative frameworks with a university-industry collaboration index of 4.2 and public-private partnerships at 4.4 highlight the region's cohesive efforts.

East Asia emerges as a global leader in innovation, driven by powerhouse economies like South Korea, Japan, and increasingly China. With the highest R&D investment (3.0% of GDP) and patent filings (900 per million people), the region demonstrates a relentless focus on technological development and industrial competitiveness. Strong collaboration frameworks, with indices of 4.3 for university-industry collaboration and 4.5 for public-private partnerships, showcase the ability of East Asian nations to integrate research and innovation into industrial and policy contexts.

In stark contrast, South Asia and Sub-Saharan Africa face significant hurdles in building competitive innovation systems. South Asia invests only 0.7% of GDP in R&D, and Sub-Saharan Africa lags further behind at 0.4%. Patent filings in these regions remain exceptionally low, with fewer than 20 patents per million people. Limited collaboration between universities and industries, alongside weak public-private partnerships (indices below 3.5 in both regions), highlights systemic challenges such as insufficient funding, fragmented institutions, and lack of infrastructural support. These constraints hinder their ability to leverage innovation for economic transformation.

Regional disparities in innovation systems underscore the need for customized strategies to address specific challenges. While advanced economies in North America, Western Europe, and East Asia can continue to focus on fostering cutting-edge technologies and global leadership, regions like South Asia and Sub-Saharan Africa require foundational improvements. Enhanced R&D funding, targeted educational reforms, and policies to strengthen institutional collaboration are critical to closing these gaps.

Natural resource-rich countries have unique opportunities and challenges when it comes to innovation and economic development. While resource wealth provides substantial economic advantages, it can also hinder diversification and innovation in non-resource sectors, a phenomenon often referred to as the 'resource curse'. The next figures highlight the innovation systems and capacities of selected resource-rich countries, focusing on key metrics such as R&D investment, patent filings, and collaboration between academia and industry.

From the data collected we can see that R&D investment emerges as a fundamental determinant of innovation performance. Norway leads with 2.3% of GDP allocated to R&D, translating into advanced innovation outputs, while Australia (1.8%) and Canada (1.6%) follow closely. In contrast, countries like Algeria (0.6%) and Saudi Arabia (0.8%) allocate minimal resources to research, limiting their ability to generate significant advancements. This disparity highlights the importance of channeling resource revenues into R&D to build diversified, knowledge-based economies.

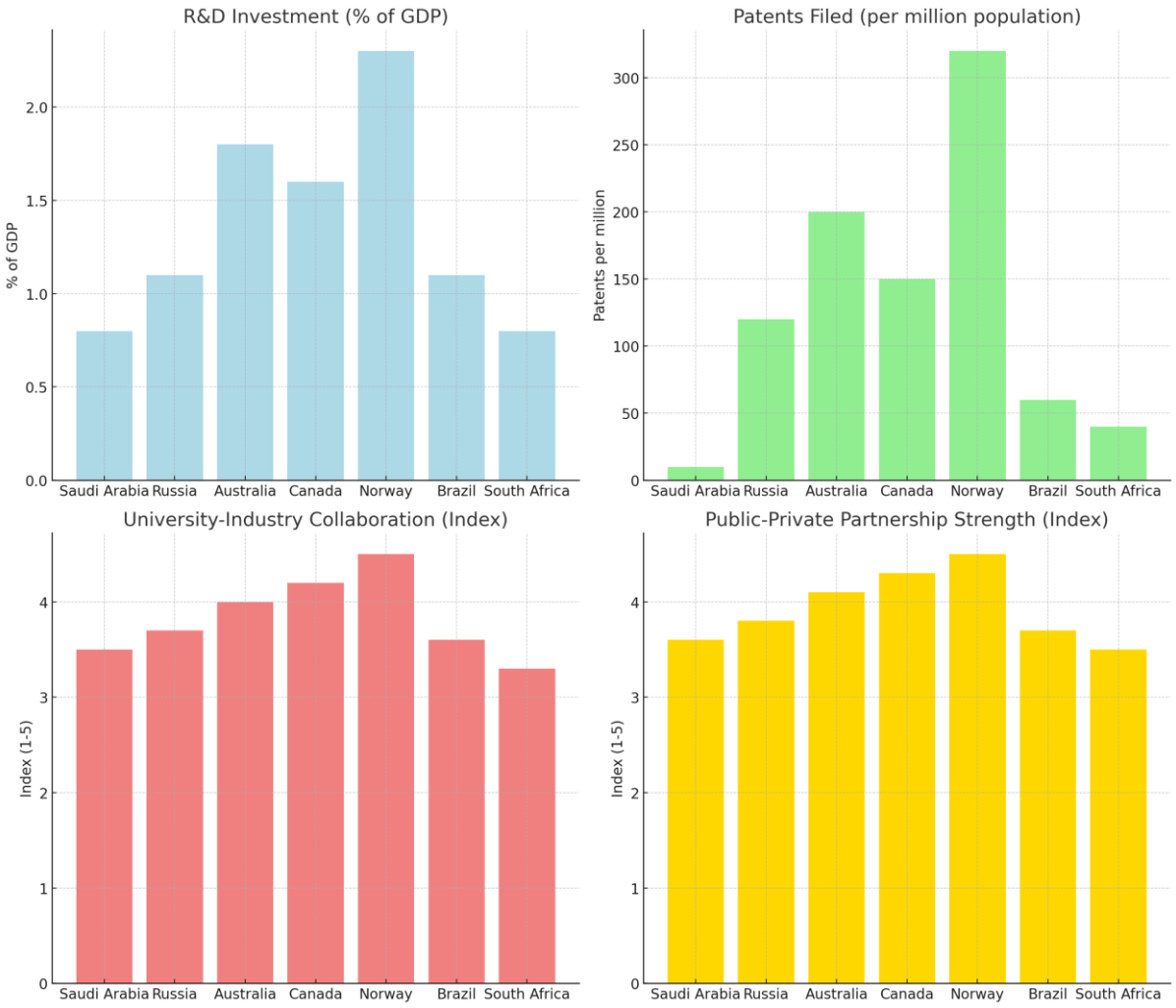

Fig. 3. Innovation and innovation capacities of some resource-rich countries
Adapted from (UNESCO Institute for Statistics, 2024) and (World Bank, 2024)

Nevertheless, patent filings per million people serve as a quantitative indicator of innovation outcomes. Norway (320 patents) and Australia (200 patents) demonstrate the capacity to transform research into marketable intellectual property. However, countries like Algeria (5 patents) and Saudi Arabia (10 patents) exhibit low patent activity, pointing to weak innovation systems. These nations face challenges in translating research efforts into tangible outputs, underscoring the need for enhanced patent facilitation and support mechanisms.

The strength of university-industry collaboration significantly impacts knowledge transfer and commercialization. Norway (4.5) and Canada (4.2) exemplify robust integration between academia and industry, which fosters a seamless flow of innovation. Algeria (3.0) and South Africa (3.3) lag in this regard, reflecting fragmented connections between research institutions and the private sector. Enhanced collaboration frameworks are essential for these nations to align academic research with industrial demands.

Moreover; effective public-private partnerships bolster innovation ecosystems by pooling resources and expertise. Norway (4.5) and Canada (4.3) leverage strong partnerships to achieve innovation synergies. Conversely, Algeria (3.2) and South Africa (3.3) exhibit weaker collaboration, hindering their capacity to scale innovative solutions. Strengthening such partnerships could unlock the potential of underutilized human and financial resources in these economies.

The findings highlight a critical lesson for resource-rich nations: leveraging natural wealth for innovation requires deliberate strategies to invest in R&D, foster collaborations, and create supportive ecosystems for intellectual property generation. Countries like Norway and Canada provide blueprints for success, while nations like Algeria and Saudi Arabia must prioritize reform to narrow the innovation gap. Ultimately, the ability to transform natural resource wealth into technological progress will determine these countries' resilience and competitiveness in an increasingly knowledge-driven global economy.

For developing regions, the challenge of building effective innovation systems is influenced by factors such as economic constraints, governance structures, and access to education and technology (see figure below). This analysis examines the innovation ecosystems of Sub-Saharan Africa, South Asia, Southeast Asia, Latin America, and the Middle East by evaluating key metrics: R&D investment, patent filings, university-industry collaboration, and public-private partnership strength. The findings provide a nuanced understanding of the disparities and commonalities among these regions.

Investment in research and development in these regions show that Southeast Asia (1.1% of GDP) leads among the regions, showcasing relatively higher prioritization of R&D activities. Latin America (0.8%) and South Asia (0.7%) exhibit moderate investment levels, while Sub-Saharan Africa (0.4%) and the Middle East (0.6%) lag significantly. These discrepancies highlight the need for policy interventions to channel more resources into R&D, particularly in regions with lower investment levels.

Data about patent filings per million population indicate that Southeast Asia again emerges as the leader with 50 patents per million, reflecting its comparatively advanced innovation system. Latin America (30 patents) and the Middle East (25 patents) follow, while South Asia (20 patents) and Sub-Saharan Africa (10 patents) show limited patent activity. The stark contrast suggests a need for better patent facilitation systems and increased focus on intellectual property protection in underperforming regions.

The effectiveness of university-industry collaboration in Southeast Asia scores highest (3.5), reflecting strong academic-industrial partnerships that align research with market needs. South Asia (3.2) and Latin America (3.1) demonstrate moderate performance, while Sub-Saharan Africa (2.8) and the Middle East (3.0) lag behind. Regions with weaker collaboration must establish frameworks to foster closer ties between academia and industry, such as innovation hubs and co-funded research programs.

In terms of public-private partnerships (PPPs); Southeast Asia (3.7) and South Asia (3.3) perform relatively well, indicating successful models of collaboration between governments and the private sector. The Middle East (3.1), Latin America (3.2), and Sub-Saharan Africa (2.9) exhibit weaker performance, underscoring the need for structured policy measures to strengthen PPPs. Enhanced collaboration can facilitate the development of large-scale projects and stimulate economic growth through innovation.

The comparative analysis reveals clear disparities among developing regions in their innovation capacities. Southeast Asia emerges as the strongest performer across all metrics, driven by higher R&D investment, stronger collaboration frameworks, and robust patent activity. In contrast, Sub-Saharan Africa shows significant gaps, particularly in R&D investment and patent filings.

Latin America and South Asia exhibit moderate performance, with room for improvement in collaboration and PPP indices. The Middle East, while slightly ahead of Sub-Saharan Africa, still requires targeted interventions to improve its innovation outputs and partnerships.

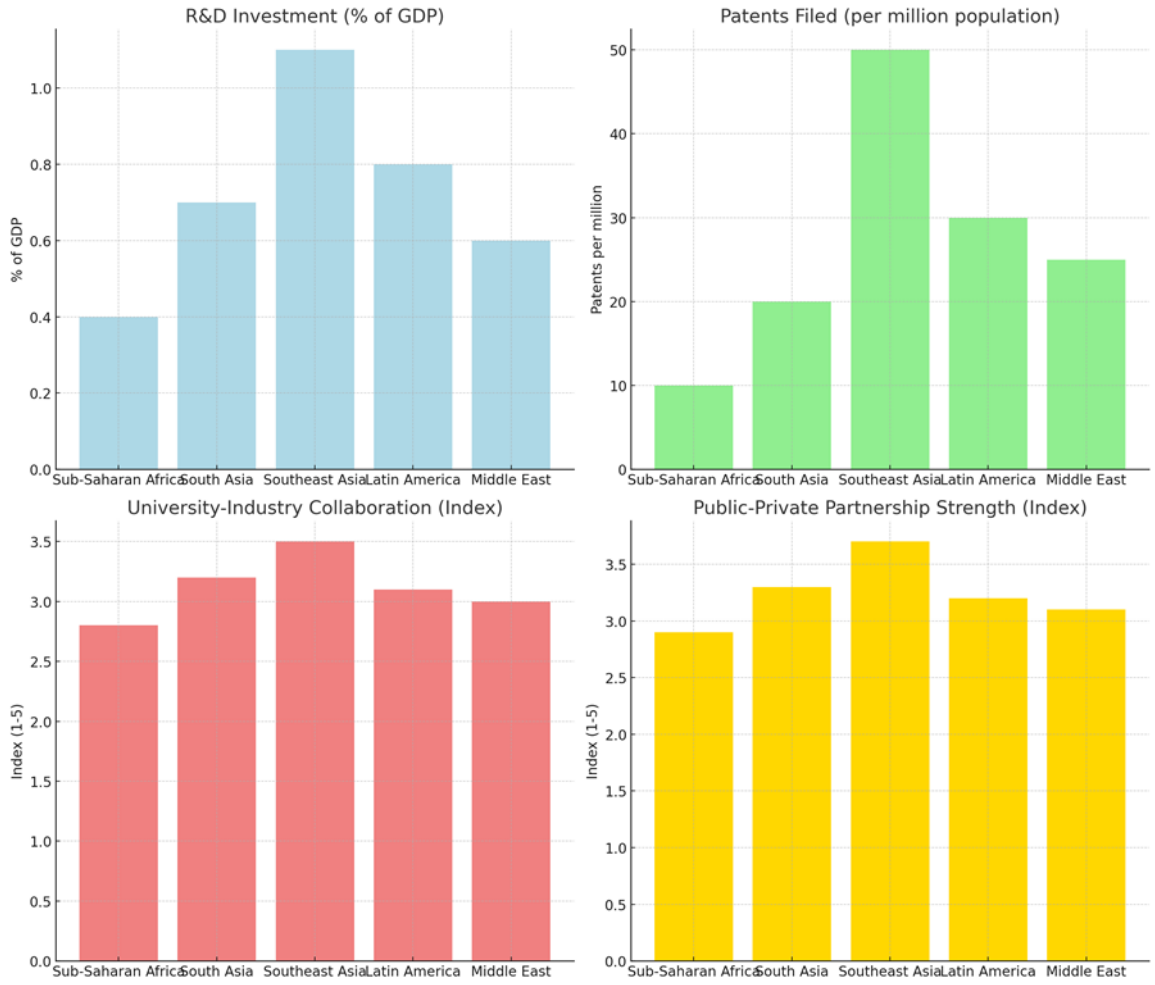

Fig. 4. Innovation and innovation capacities measures of developing regions
Adapted from (UNESCO Institute for Statistics, 2024) and (World Bank, 2024)

The analysis underscores the critical role of strategic investment, collaboration, and policy support in building resilient innovation ecosystems. Regions like Southeast Asia serve as benchmarks for developing nations, demonstrating how focused efforts can yield measurable progress. Southeast Asia is shown as the strongest performer among developing regions in terms of innovation capacity, driven by higher R&D investment and effective collaboration mechanisms. Sub-Saharan Africa and South Asia face significant challenges in these areas. By adopting targeted strategies to increase investment, foster partnerships, and build human capital, these regions can enhance their innovation systems and drive sustainable economic growth.

CONCLUSION

Building robust innovation systems is not merely a pathway to economic growth but a necessity for addressing the complex challenges of the 21st century. Nations that prioritize innovation are better equipped to respond to global competition, adapt to technological disruptions, and achieve sustainable development. By learning from successful models and implementing targeted reforms, resource-rich and developing nations can transition from dependency to innovation-driven prosperity, securing a more stable and inclusive future for their populations.

The comparative analysis of innovation systems across different regions and countries underscores the pivotal role of National Innovation Systems (NIS) in fostering innovation capacity

and driving sustainable economic growth. Leading innovative nations demonstrate that the success of an innovation ecosystem relies on a combination of strong institutional frameworks, effective government policies, and robust collaborative networks that link academia, industry, and the public sector. These systems enable the efficient flow of knowledge, resources, and technology, which are critical for fostering creativity, producing groundbreaking innovations, and translating research into economic and social benefits.

Resource-rich nations present a particularly complex case. While endowed with natural wealth that theoretically provides an economic advantage, many of these countries remain trapped in cycles of dependency and stagnation due to insufficient investment in R&D, weak public-private partnerships, and underdeveloped educational and technological infrastructure. The phenomenon known as the "resource curse" highlights how reliance on natural resources can crowd out innovation by discouraging diversification and reducing incentives for technological advancement. However, examples such as Norway and Canada illustrate that resource wealth, when managed strategically, can serve as a catalyst for innovation. By reinvesting resource revenues into education, research, and technology-driven industries, these countries have successfully diversified their economies and built resilient innovation systems.

Developing regions, on the other hand, face unique challenges in building innovation capacity. Limited access to funding, fragmented institutional frameworks, and inadequate infrastructure hinder their ability to foster dynamic innovation ecosystems. Sub-Saharan Africa, South Asia, and Latin America, for instance, exhibit lower levels of R&D investment and patent activity, reflecting systemic constraints that impede progress. However, these regions also possess significant untapped potential, including growing populations, increasing integration into global markets, and emerging industries that could drive future innovation. By addressing structural barriers and leveraging these opportunities, developing regions can position themselves for long-term technological and economic advancement.

A critical takeaway from this research is the importance of targeted investments in R&D and human capital as foundational pillars for enhancing innovation capacity. Governments must prioritize funding for sectors with high potential for technological breakthroughs, including renewable energy, biotechnology, and digital industries. Furthermore, fostering robust university-industry collaborations and public-private partnerships is essential for creating an environment where research outputs can be effectively commercialized. Examples from Southeast Asia demonstrate how aligning academic research with industrial needs can significantly enhance innovation outputs and accelerate economic growth.

Another crucial factor is the role of education in building a skilled workforce capable of driving innovation. Investments in STEM education, entrepreneurship training, and vocational programs are necessary to equip individuals with the technical and creative skills required to thrive in a knowledge-driven economy. Additionally, creating innovation clusters—geographical concentrations of research institutions, industries, and infrastructure—can amplify knowledge spillovers and foster synergies that boost innovation capacity. Countries like Malaysia, with its Multimedia Super Corridor, provide a blueprint for leveraging innovation clusters to achieve economic transformation.

Finally, policymakers must recognize the systemic nature of innovation. A well-functioning NIS requires continuous collaboration among stakeholders, clear governance structures, and policies that incentivize risk-taking and experimentation. The lessons drawn from leading innovative countries highlight the need for adaptive strategies that respond to the specific cultural, economic, and institutional contexts of each nation. For resource-rich and developing countries, overcoming structural barriers and fostering an innovation-centric mindset are critical for achieving long-term resilience and global competitiveness.

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ЗВ'ЯЗОК НАЦІОНАЛЬНИХ ІННОВАЦІЙНИХ СИСТЕМ ТА ІННОВАЦІЙНОГО ПОТЕНЦІАЛУ

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Національні інноваційні системи (НІС) є основоположними у формуванні інноваційного потенціалу країни, впливаючи на економічну диверсифікацію та стійке зростання. Метою цього дослідження є вивчення ролі структурованої та функціональної НІС у сприянні інноваційному потенціалу в різних контекстах, включаючи багаті на ресурси країни, провідні інноваційні країни та регіони, що розвиваються. У цьому дослідженні використовується методологія порівняльного аналізу, спираючись на дані глобальних індексів інновацій, тематичних досліджень і академічної літератури для оцінки ключових показників, таких як інвестиції в дослідження та розробки, патентна діяльність, співпраця між університетами та промисловістю та державно-приватне партнерство. Отримані результати показують значні відмінності в ефективності інновацій: багаті на ресурси країни часто стримуються системними проблемами, такими як «ресурсне прокляття», а такі країни, як Норвегія та Канада, ілюструють, як стратегічне управління природними багатствами сприяє сталим інноваціям. Подібним чином регіони, що розвиваються, стикаються з бар'єрами, включаючи слабкі інституційні рамки та обмежене фінансування, але демонструють потенціал для прогресу через цілеспрямовані реформи. Висновки підкреслюють важливість надійних структур НІС, наголошуючи на необхідності збільшення інвестицій у науково-дослідні роботи, тіснішої співпраці між університетами та

промисловістю та розширеного державно-приватного партнерства як ключових факторів розвитку інноваційного потенціалу. Практичні та політичні наслідки необхідні для того, щоб запропонувати дієві стратегії для подолання системних проблем, покращення інноваційних екосистем і досягнення економічної стійкості.

Ключові слова: національні інноваційні системи (НІС), інноваційний потенціал, інноваційні екосистеми, дослідження та розробки (НДДКР).