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Research Article

Measuring Innovation Capability on National Level: Challenges and Solutions

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Abstract – This paper examines the challenges of measuring national innovation capability, focusing on infrastructure, human capital, and research and development (R&D). While infrastructure supports innovation, assessing human capital is difficult due to its intangible nature, and R&D's impact is hard to quantify. Current indices like the Global Innovation Index fail to capture the full complexity of innovation capability. A key challenge is the lack of research on the conditions that foster innovation, as well as the influence of cultural differences. The paper proposes a more nuanced approach to measurement, combining quantitative and qualitative data to address these complexities and offer practical solutions for improving innovation measurement and policy.

Keywords – Innovation Capability; National Level; Measuring; R&D; Human Capital; Infrastructure; Challenges; Solutions.

I. INTRODUCTION

The ability of a nation to manage resources and expertise to convert existing knowledge into new knowledge, technology, and creative outputs for the benefit of businesses, industries, and the national economy as a whole is referred to as national innovation capability (Fagerberg and Srholec, 2008). Due to increasing global competition in science and technology, nations are increasingly recognising the importance of enhancing their performance in innovation activities to achieve sustainable and effective development (Dzhunushalieva & Teuber, 2010). National innovation capability is now seen as a critical driver of economic growth, technological advancement, and global competitiveness. As such, understanding the factors that contribute to innovation capability at the national level has become a central concern for policymakers, businesses, and academic researchers alike.

Several studies in the literature have examined the concept of national innovation capability, focusing on various aspects such as infrastructure, human capital, research and development (R&D), and policy frameworks. However, measuring innovation capability presents significant challenges, particularly due to its complex and multidimensional nature. These challenges include the intangibility of certain factors like human capital, the lack of comprehensive data, and the influence of cross-cultural variations on innovation systems. In addition, existing measurement tools, such as indices and scoreboards, often fail to fully capture the depth and diversity of national innovation ecosystems.

This paper aims to investigate the challenges and solutions proposed in the literature regarding the measurement of national innovation capability. The research question driving this study is: What are the

key challenges associated with measuring innovation capability on the national level, and what practical solutions have been proposed to address these challenges in the literature? Through this exploration, the paper seeks to provide valuable insights into improving the methods used to assess and enhance innovation capability at the national level.

II. MATERIALS AND METHOD

The primary objective of this study is to identify key challenges in evaluating innovation at the national level and explore the solutions proposed in the literature.

Literature selection was based on its relevance to the measurement of national innovation capabilities. Sources included peer-reviewed journal articles, academic books, and reports from respected institutions. The literature was gathered from established academic databases such as PubMed, Scopus, Web of Science, and Google Scholar, ensuring a wide range of academic perspectives and methodologies. Emphasis was placed on recent publications to capture the latest trends and developments in the field, reflecting the evolving nature of innovation research.

A systematic search strategy was applied using various combinations of keywords such as "innovation capability," "measurement," "national innovation," "R&D spending," "human capital," "patents," and "infrastructure." This approach ensured that the review covered a broad range of topics, including key elements of innovation capability. Manual searches of reference lists from relevant articles were also conducted to identify additional pertinent sources.

The selection criteria focused on including studies that specifically addressed the measurement of innovation capabilities at the national level. Only studies that offered theoretical or empirical insights into measurement frameworks, concepts, or factors influencing national innovation capability were considered. Research concentrating on specific sectors was included if it provided broader implications for understanding national innovation systems. Articles published in languages other than English were excluded due to translation limitations, ensuring consistency in the analysis.

Once the literature was selected, the articles were analysed qualitatively to extract key themes, concepts, and measurement frameworks. The analysis was organized thematically to identify the main challenges in measuring national innovation capability and the proposed solutions and methodologies. The synthesis aimed to uncover recurring patterns, research gaps, and emerging trends, offering a comprehensive overview of the current state of research. Additionally, the study highlighted areas where further research could enhance measurement methods and deepen the understanding of national innovation systems.

Through this methodology, the study provides a critical evaluation of the literature on national innovation capability measurement, offering valuable insights for policymakers, researchers, and practitioners seeking to improve innovation measurement frameworks.

III. RESULTS

A. Infrastructure and Innovation Performance

A healthy and established technological and physical infrastructure is essential in enhancing the innovation of businesses in a country. According to Pan et al. (2021), a conducive technology infrastructure boosts technological innovation and then promotes countries' economic development. For example, Jabbouri et al. (2016) found a positive and significant relationship between technological infrastructure and innovation performance in Iraq. Moreover, Tsetim et al. (2020) indicate that infrastructural dimensions, which include technology and structure, had a significant relation to the innovativeness of SMEs in Nigeria. In order for a state to successfully innovate at a national level, it has to be technologically caught up with the global systems. Such technological catch-up can be defined as accumulative innovative capability (Figueiredo and Cohen, 2019). The countries which are new to the innovation world may decrease the gap between the technological tools they use in production and the ones that are used by global leaders on the

international stage through accumulating technological and innovational capabilities. Moreover, later, these countries may even catch up with global innovation leaders in terms of capabilities, generate or make changes to the technologies they own, and engage actively in global innovation activities (Figueiredo, 2014). The primary factors that affect the technological catch-up are pre-existing knowledge and comprehension, vigorous Research and Development endeavours, a combination of internal R&D projects and expertise coming from abroad as well as state support through governance, funding, scholarly studies, and education (Majidpour et al., 2021). As per Lee and Lim (2001), technological catching-up has three distinct patterns. The first one is a path-following catch-up, which implies that the state is following the same methodology and technology implementation as leader-countries. In the second scenario, the latecomer bypasses certain stages in order to catch up. This approach is beneficial in terms of saving time. Lastly, the third pattern's main characteristic is that the latecomer explores one's own technological development path. It should be mentioned that it is also possible to implement a combination of these three patterns. In the last two patterns, a leapfrogging element can be observed (Lee and Lim, 2001). According to Dowrick (1992), the idea of technological catch-up is related to the concept of efficiency and incorporating efficiency. His study revealed that less developed economies that mimic the production methods utilized by more developed countries may not be successful if they are unable to assimilate and apply new concepts due to a lack of social and technological capacity.

B. Human Capital and Innovation Performance

According to the OECD, the definition of human capital is the expertise, abilities, competencies, and other characteristics incorporated into individuals which are pertinent in terms of economic activity (1998). Most typically, human capital is presented as expertise obtained through studying and practice. Potelienė and Tamašauskienė (2014) gave the following summary of the characteristics of human capital–health, talent, erudition, skills, expertise, tendencies in migration, intuition, personal values, and capability to understand the overall goals of the nation, conditions of the labour market, entrepreneurial skills, and ethics. The general framework of human resources concentrates on the economic behavioural patterns of a person, particularly how the aggregation of knowledge and expertise helps them to boost their performance and income, and consequently, boost the performance and financial resources of the societies where they live (Rosdi & Chew, 2010). Human capital assessment may be a challenging task as this resource has an intangible nature. On an international scale, this task becomes even more complicated and has way more restraints as it is hard to indicate assessment methodologies of human capital that will be corresponding, especially time-wise. With regard to human capital measurement, three main strategies can be accentuated (Oxley et al. 2008):

- Cost-based approach
- Income-based approach
- Education-based method

Giménez et al. (2015) concluded that there are three main reasons why the education-based approach is most frequently utilized in macroeconomic studies: first, it is based on the idea that formal education is the primary source of acquiring human capital; second, there is a strong correlation between this approach and other acquisition ways; and third, there is a presence of comparable international data.

Moreover, Woessmann (2003) suggested that the most widely used measures of human capital include rates of adult literacy, average years of education, school enrollment rates, and indices of the quality of education.

C. Research & Development in National Innovation Capability

R&D (Research and Development) refers to the human, material, and financial resources required to participate in scientific research and experimental development activities. R&D expenditure and its proportion in GDP reflect the important content of the country’s independent innovation capability.

UNESCO believes that R&D is a systematic creative activity that uses new knowledge to generate new applications. In addition, the OECD (Organization for Economic Cooperation and Development) also believes that R&D is a more systematic and creative activity. This type of activity is based on increasing the total amount of knowledge and using that knowledge to create new applications (Biel, 2023).

It is noteworthy to differentiate national innovation capability from national innovation capacity. The former displays underlying indicators of the innovational process, and the degree of innovation output is not defined (Furman et al., 2002). However, the latter involves technical expertise, like articles and patents, as well as original outcomes, like exports of innovative services and applications of trademarks (Khedhaouria and Thurik, 2017).

Fagerberg and Srholec (2008) believe that at the national level, the differentiations in the states' capability to fully utilize the potential to align with the rest of the world may be clarified in larger a dimension, called social capability. Social capability has the following aspects:

- Competence in technology and administration
- A balanced and efficient government to yield economic growth
- Monetary organizations and a market, that has the feasibility to mobilize capital at a broader scope
- Significant integrity and reliability in the society

According to Dang and Umemoto (2009), there are three categories of national innovation capability: 1) Epistemological; 2) Economic; 3) Institutional. All of these demonstrate three elementary aspects of the economy that are based on expertise and knowledge. Knowledge may be considered in three ways, firstly, as an asset (tangible inputs and outputs in economy), secondly, as a relationship (social ties, engagements, and interconnected systems) and lastly, as a capability (organizational capabilities as well as social ones of a state).

D. Measurement through Indexes and Analytics Systems

Numerous innovation indexes measure national or regional innovation capability, but considering the evaluation framework across distinct innovation stages and components would add more value.

One of the statistical techniques that is also frequently used to assess the effectiveness of national innovation systems is data envelope analysis or DEA. Sharma and Thomas (2008) investigated the connection between the following variables: output variables, such as the number of publications for 22 nations, and resident-granted patents, and input variables (research spending and researchers per million population). They discovered that the number of researchers and R&D expenditures had a major influence on the output variables. Pan et al. (2010) used the mutual DEA model to assess the National Innovation system's performance in 33 Asian and European nations. The overall amount of funding spent on R&D and education, the total number of employees engaged in R&D, and the importation of goods and services are regarded as input elements, while the number of patents and scientific papers are considered as output factors. In addition to determining the impact of input variables on output, they also found through bilateral comparison analysis that the input factors from the Asian group overtook those in the European group.

National Innovation System (NIS) was introduced in the pre-dot-com bubble era (Dosi, G. et al. 1988) and represented a systematic view to measure innovation capability at a national level (Lundvall, B.-Å. (2010).

The basic idea behind a national system of innovation is that different countries are experiencing different levels of innovation. The key widespread index utilized by the majority of the countries is the Global Innovation Index (GII), which measures innovation considering possible unpredictable geopolitical and economic landscapes. It should be noted that GII exploits prior research and accurately captures the state of knowledge regarding NISs and the mechanisms underlying their operations. It also makes use of precise measurement instruments and examines both its primary data and final indicators for numerous internal and external tests. It regularly releases thorough data that covers the innovation performance of about 132 economies and highlights the advantages and disadvantages of innovation. It determines the most innovative economies in the world (WIPO, 2023).

In order to compare and evaluate the research and innovation performance of EU Member States, other European nations, and their regional neighbours, another indicator, the European Innovation Scoreboard may be utilized. It facilitates countries in assessing the advantages and disadvantages of their national innovation systems and locating issues that require attention (European Commission, 2024). This scoreboard has three dimensions which are outputs, company activities, and enablers, and these comprise various system indicators. As a result, the national innovation systems of the European Union's member states are divided into four performance categories: Innovation leaders, Strong innovators, Moderate innovators and Emerging innovators. (European Commission, 2024).

Another example is the Knowledge Assessment Methodology (KAM), which was created by the World Bank to measure a country's innovation capability. This technique unified indicators under the following four categories:

- The Economic Incentive and Institutional Regime
- Education
- Innovation
- Information and Communications Technologies (ICT).

As a result, the Knowledge Index (KI) and Knowledge Economy Index (KEI) were created (Karahan, 2012, 23). Additionally, the Science, Technology, and Industry (STI) Scoreboard has been developed by the Organization for Economic Co-operation and Development (OECD). These are the five key points that summarize analyses related to the member nations in the Scoreboard (OECD, 2015):

- Investing in Knowledge, Talent and Skills
- Connecting to Knowledge
- Unlocking Innovation in Firms
- Competing in the Global Economy
- Empowering Society with Science and Technology

Another index, which is also implemented outside of the global economic institutions, is "The ARCO Technology Index" which was developed by Archibugi and Coco in 2004. In order to generate complex metrics, they factored in three facets of technology: technological infrastructure, human resources, and innovative operations. The studied data covered a decade between 1990 and 2000 and analyzed 162 various states.

Apart from this, Choi and Zo (2019) addressed the issue of national innovation effectiveness in developing countries scrutinizing the steps of knowledge production (cost and R&D as inputs, the patents and number of scientific articles as outputs) and the knowledge implementation (patents, number of scientific articles, imports of high-tech goods, and foreign investment rate as inputs and start-up businesses concentration, productivity, and intermediate and advanced technological productions as the outputs).

IV. DISCUSSION

A. Restraints Faced by National Innovation Systems

There is not abundant information on the precise conditions which contribute to higher levels of national innovation capability, despite extensive research on the subject. Several theoretical studies have been conducted and for example, evaluations of research on national innovation capability reveal that individual studies only address a small part of the innovation conditions (Fagerberg and Srholec, 2008). This is important because from the national innovation system perspective (Lundvall et al., 2002) national innovation capability is systemic and results from an evolutionary learning process that leads to coherent outputs. Moreover, the majority of empirical research on innovation and expansion has not yet addressed a couple of crucial topics. The first is that, although a significant amount of research has been conducted to analyze how innovation affects economic growth, little attention has been paid to finding out the factors that facilitate national innovative activities (Castellacci, 2011).

Secondly, while we acknowledge technology's pivotal role in growth, contemporary literature also underlines that technological advancement comes at a high cost. This point of view implies that nations

should be prepared for their continued technological backwardness if they cannot build the necessary capabilities and other supportive elements.

When firms consider adopting big data analytics, one of the most critical issues that needs to be addressed is data availability. Data availability refers to the continuous availability of the required data when and where they are needed (Robin, 2023). However, some businesses are more critical to data availability than others. Thus, storing data on clouds and servers can contribute to data availability issues. In this regard, all data sources, like systems, devices, machines, and sensors, must be integrated with big data analytics (Cadersaib, B.Z., 2018).

B. Effects of Cross-Culturalism on National Innovation Capability

Country-specific attributes are essential for consideration when trying to measure the innovation capability of a country since the same industry may grow and function differently in different states' systems. These attributes can be highlighted through the difference in national culture for each state. National culture is a term used to explain a state's major tendencies in terms of specific values, beliefs, principles, dispositions, and choices (Hofstede et al., 2010).

Since national innovation systems are integrated into a larger socio-economic landscape, national culture is of great importance as it has a substantial impact on the results of a country's established organizations, like economic prosperity, business innovation, or national innovation performance (Taylor & Wilson, 2012).

Hofstede's framework of national culture is regarded as a reliable and efficient tool used to quantify national culture in a comparatively substantial number of countries (Kirkman et al., 2006). It indicates five (originally, four) cultural dimensions that create unprecedented profiles of national culture.

The first dimension of national culture is a power distance which refers to the extent to which members of a society forecast and acknowledge irregular allocation of authority (Hofstede et al., 2010). A low degree of power distance fosters equality, decentralized structures, and delegated decision-making, promoting supportive organizational attributes like reduced hierarchy, less supervision, and more informal interactions, which contribute to higher national innovation performance. (Hofstede et al., 2010).

The second cultural dimension– individualism versus collectivism– has been the centre of scrutiny in research on cross-culturalism (Chen et al., 2009). Individualism emphasizes personal benefit and close family ties within a loose societal structure, while collectivism focuses on an individual's dedication to a broader group within a tightly-knit society (Hofstede et al, 2010). Indeed, individualism is considered a precursor of high national innovation performance, as opposed to collectivism, which is believed to hinder innovation processes by demanding individuals to adapt to the institutional guidelines, adhere to established parameters and conduct in accordance with the firmly established procedures (Taylor & Wilson, 2012).

Hostede's third cultural dimension- masculinity versus femininity–has had mixed theoretical premises in prior cross-cultural research. Both masculine values, like career success and monetary incentives, and feminine values, such as strong interpersonal connections and support, are seen as indicators of high national innovation performance—masculinity fostering an ambitious, results-driven environment, and femininity promoting collaboration and support (Efrat, 2014).

The fourth cultural dimension, which is escaping uncertainty, represents the extent to which the members of a society are avoiding uncertainty and ambiguity (Hofstede et al., 2010). A levelled degree of uncertainty avoidance is anticipated to yield an organizational setting that is linked to risk aversion, fear of failure, and resistance to unconventional concepts and attitudes. While, a low degree of uncertainty avoidance is regarded as a sign of high national innovation performance because it supports innovative attitude and original concepts, acceptance of risk and adaptability, reduced authority, and more implicit rules and frameworks (Efrat, 2014).

Ultimately, the fifth dimension—long-term orientation—reflects a community's focus on future goals, practicality, and perseverance, while short-term orientation emphasizes past and present values, cultural heritage, and societal standards (Hofstede et al., 2010). While alluding to outcomes and attainment as long-

term ideas, contemporary research has factored in the future-focused cultural framework as an indicator of high national innovation performance (Efrat, 2014).

C. Intangible Nature of Innovation

A substantial amount of data-driven research on the connection between innovation and productivity enhancement takes a deeper look into research and development indicators (A. Bassanini, S. Scarpetta, 2001). The problem is that such concentration on R&D expenditures does not fully encompass the intangible nature of the innovation capability. This concentration on research and development can be evidently seen in the strategy "Europe 2020" (European Commission, 2010) which aims to reach intelligent, resilient, and economically broad-based development. This strategy suggests cultivating innovation by reaching a benchmark of 3% as a share of GDP allocated on R&D investments by each of the member states. This concept of allocating 3% of GDP to R&D had previously been developed in 2000 in the Lisbon strategy and apparently, this is the sole standard that has passed over from the initial Lisbon strategy (European Commission, 2010).

On the other hand, negative feedback on implementing a 3% benchmark has already been shared (Tilford S., Whyte P., 2010). Such feedback is firmly grounded on the fact that investment in Research and Development does not appear to be a reliable metric of a state's innovation capability. It is appropriately asserted that R&D measures are of paramount significance for the states where the production industry is stronger, for example, in Germany, but it can be readily overlooked in the countries where service sectors are of higher importance and efficiency, for instance, the UK (Tilford S., Whyte P., 2010).

D. Solutions

To effectively measure national innovation capability, several advanced methodologies and data-driven tools can be employed, offering deeper insights into the dynamic nature of innovation systems such as bibliometric analysis, big data analytics, social network analysis (SNA) AND Social Media Sentiment and User-Generated Content (UGC) Analysis.

Bibliometric analysis helps track the development and trends in innovation research by analyzing academic publications, citations, and reference networks. This approach offers a more objective, comprehensive view of innovation, highlighting key developments and research gaps (Dahesh et al., 2020).

Big data analytics utilizes unstructured data from digital platforms, sensors, and social media. Advanced techniques like machine learning and text mining help uncover patterns and trends in innovation, providing real-time insights into a national innovation system’s performance (Dedic and Stanier, 2016).

SNA maps relationships among innovation actors (e.g., businesses, universities, and government) to uncover collaboration patterns and assess the structure of innovation systems. It helps identify key players and analyze how network dynamics impact innovation outcomes (Gijsbers, 2010).

Analyzing UGC from social media platforms provides real-time insights into public sentiment, emerging trends, and consumer preferences. This data can guide innovation strategies by identifying societal needs and public interest in specific technologies or policies (Naeem & Okafor, 2019). A substantial amount of data-driven research on the connection.

V. CONCLUSION

A number of variables, including infrastructure, human capital, R&D expenditure, and the intangible character of innovation, affect how difficult it is to measure a country's capacity for innovation. National innovation systems' (NIS) efficacy is frequently hindered by issues like as scarce resources, cultural disparities, and the difficulty of measuring intangible assets like creativity and knowledge. However, innovative solutions are emerging to address these challenges.

Methods such as bibliometric analysis, big data analytics, and social network analysis (SNA) offer valuable tools for tracking trends, collaboration patterns, and technological advancements within

innovation systems. Furthermore, real-time insights into public opinions and new opportunities can be gained through the analysis of user-generated content (UGC) and sentiment on social media. A more thorough and dynamic picture of a country's capacity for innovation can be achieved by combining these methods with more conventional metrics like R&D investment and innovation indices. In conclusion, even though assessing innovation at the national level presents many difficulties, using data-driven solutions and sophisticated analytics can improve the precision and applicability of innovation assessments, leading to better policy choices and more robust innovation ecosystems.

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