Measuring Science and Technology Innovation Capacity in Developing Countries: From a National Innovation System

Haeng A. Seo, Changseok Oh, Seung Jun Yoo

***Abstract*—**This study attempts to examine the disparities in S&T innovation capacity from 14 developing countries to discuss how to support specific features in national innovation systems. It includes East-Asian, Middle-Asian, Central American and African countries. Here, we particularly focus on five dimensions- resources, activities, network, environment and performance- with 37 indicators. They were derived as structuring components of the relevant diagnostic model, which encompasses the whole process of S&T innovation from the input of resources to the output of economically valuable results. For many developing nations, economic industries remain weaker than actual S&T capabilities, and relevant regulatory authorities may not exist. This paper will be helpful to provide basic evidence and to set directions for better national S&T Innovation capacities and toward national competitiveness.

***Keywords*—**Developing countries, measurement, NIS, S&T innovation capacity.

I. Introduction

In the last century, innovation within S&T fields has become a core driver of national competitiveness, and competitiveness has become a frequently used gauge of national productive capacity. *National innovative capacity* is a country's potential—as both a political and economic entity—to produce a stream of commercially relevant innovations [1]. When specifically applied on the science and technology (S&T) sector, the concept can be denoted by S&T innovative capacity. Innovative capacity can be evaluated by examining country's *national innovation system (NIS)*. A system of innovation refers to the interacting components required for the creation, dissemination, and application of economically useful knowledge, and the relationships between them [2].

In recent years, many developing countries have attuned their interests to S&T capability. The OECD (1999) examined various roles of the main actors in innovative processes (firms, public and private research organizations, and government and other public institutions), and the forms, quality, and intensity of their interactions. These actors are influenced by a variety of factors that exhibit some degree of country specificity: the financial system and corporate governance, legal and regulatory framework, the level of education and skills, the degree of personnel mobility, labor relations, prevailing management practices, etc. [3]. Porter and Stern use a national innovative capacity framework to guide empirical exploration into the determinants of country-level R&D productivity, specifically examining relationships in international patenting [1].

These days, many nations have offered guidance and consultation in the realm of R&D to assist developing countries in improving relevant economic and social policies. However, it is still relatively rare to find research focused on developing countries.

The current study aims to provide a precise evaluation of the S&T climate in a range of developing countries, with a description of their strengths and weaknesses to identify an appropriate direction for innovation policy. We apply existing S&T innovative capability indicators to developing countries and analyze unique features and challenges for each.

This paper is divided into five sections, exempting the introduction. The second section provides a literature review of previous attempts at measuring innovative capacity. The third section introduces the framework that is used to identify characteristics of developing countries needed to evaluate their innovative capacity. The fourth section elaborates on the study's results. Lastly, we outline each country's strengths and weaknesses in relation to its innovative capacity.

II. S&T Innovative Capacity Review

Much can be gleaned from studies that aim to understand between-country differences in the S&T field. Such research can be differentiated into two groups: those that use statistical methods to identify key players within a NIS, and those that examine case studies to analyze the barriers to innovation that may be faced by developing countries.

In the majority of cases, the use of indicators and available data is preferred over theoretical inference. The most representative available index is developed by the OECD. They publish a STI Scoreboard and its own Main S&T Indicators, supplying foundational S&T materials [4], [5]. Otherwise, the International Institute for Management Development (IMD) also incorporates indicators for technological infrastructure and scientific infrastructure as part of their economic index, generally incorporating measures for IT development, R&D investment, and population demographics [6]. The World Economic Forum (WEF) sector evaluation considers S&T

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merely as a factor in creating effective infrastructure. It seems a more systematic, comprehensive set of S&T indicators is needed [7].

Based on the basic NIS framework, the Korea Institute of Science & Technology Evaluation and Planning (KISTEP) has defined national S&T innovative capability as a nation's ability to produce economically and socially valuable improvements through innovation in S&T. We implement an evaluation index that distinguishes 5 dimensions: Resources, Activities, Network, Environment, and Performance [8].

When examining studies on policies that support developing countries, ADB provides guidelines for each donor country to support a recipient country based on its government's medium- to long-term plan and budget [9]. USAID provides execution guidelines for a project's aims, management and evaluation, based on a variety of factors such as the recipient country's development status, long-term challenges and opportunities, monitoring assessments, and program resources and priorities [10]. Using an extended system of deductive logic, outcome assessments are used to select the most significant target, as well as sector-specific goals and sub-indicators. The World Bank conducts analyses of major development projects, government programs, partner support, strategy implementation, and lessons learned. For example, the World Bank's report on its Uganda S&T innovation project uses the national system of innovation [11].

An index applied by Ramon Padilla-Perez to assess S&T innovation policies in several Central American countries examined three distinct areas: institutional framework, financing, and interaction-diffusion [12].

As summarized above, most statistical studies have centered on developed countries, while studies on developing countries have experienced a scarcity of data and have focused instead on policy consulting. KISTEP's Composite Science and Technology Innovation Index (COSTII) index will be used in the present study to statistically analyze and compare the national S&T innovative capacities of developing countries. This method has been used annually to evaluate OECD member countries since 2006.

III. Methodology

S&T innovative capacity index of evaluation refers to reliable and concise statistics or materials that allow for a precise description of the overall state and progress of a nation's S&T innovative capacity. The index used in this study structures the general economic production process into the dimensions: Resources, Activity, Network, Environment, and Performance, and is hierarchically organized into five dimensions, 12 sectors, and 29 quantitative and eight qualitative indicators. However, because the COSTII is oriented for analyzing developed countries, modifications are needed to make it appropriate for use in the present analysis. We have replaced several indicators with items more applicable for the present purpose. We calculated an S&T innovative capacity score for each country, and conducted a comparative analysis to obtain assessment results. The indicator scores were aggregated to obtain the sector scores, which in turn were added to yield the dimension scores, and finally the COSTII for each country. The dimensions were broadly grouped as follows: Resource and Activity under Input; Network and Development under Support; and Performance under Outcome.

The Resources dimension measures the resources available to facilitate innovation. They assess three sectors: human resources, organization, knowledge resources. The Activity dimension measures how robustly the principal agents of innovation create and apply new knowledge, taking into account R&D investment and entrepreneurial activity. The Network dimension describes the effectiveness of the network of principal agents for innovation through collaboration. The Environment dimension shows how well aspects, such as systems of social support, physical infrastructure, and education facilitate innovative processes. The Performance dimension reflects the overall outcomes of national innovation, calculated from added value per capita, exports in high-tech manufacturing, licensing fees per million, number of research papers, and number of patents. This analysis is designed to measure the innovative capacity of participant countries in terms of related indicators, as well as show each country's relative stance in capacity.

Several procedures were followed to maximize the reliability of the final calculation of country indices. Given that datasets often tend to be incomplete for developing countries, minimum indicator coverage was set at 70%, with at least 50% of indicators in each dimension secured. In order to calculate a composite index and make international comparisons, indicators were standardized at the same scale to overcome their differences in measurement units and distribution. This re-scaling produced a standardized value for each country, equaling the difference between absolute value and lowest value, all divided by the difference between the highest value and lowest value. The country with the highest value in a specific indicator was designated the value 1, and the lowest the value 0.

Missing data were replaced by values from up to two years previous. If data was not available for the two preceding years, the mean value of the raw data over the last five years are used instead. In addition, only values after 2009 was considered for this study. In the case that post-2009 data did not exist, data was estimated by means of linear regression analysis of older data. If no data was available for an indicator making linear regression impossible, the mean value of other indicators within the same sector was used. All indicators were weighted equally within each dimension, but each dimension was weighted differently according to the "group" classification. The five sector indices were combined to produce the final COSTII.

Per capita GDP and number of dissertations per million was used as an indicator of countries' level of development and group them accordingly, in order to better identify policies that would suit their idiosyncrasies. The 14 sampled countries are spread over Southeast Asia, the Middle East, South America, and Africa. They were categorized as follows:

– Group 1: Qatar, Oman, Malaysia, Iran, Jordan, Egypt, Costa Rica

– Group 2: Vietnam, Philippines, Dominican Republic
– Group 3: Gambia, Uganda, Ethiopia, Malawi

Group 1 has the highest output, while Group 3 has the highest input. This grouping was implemented since output and input vary with development standing.

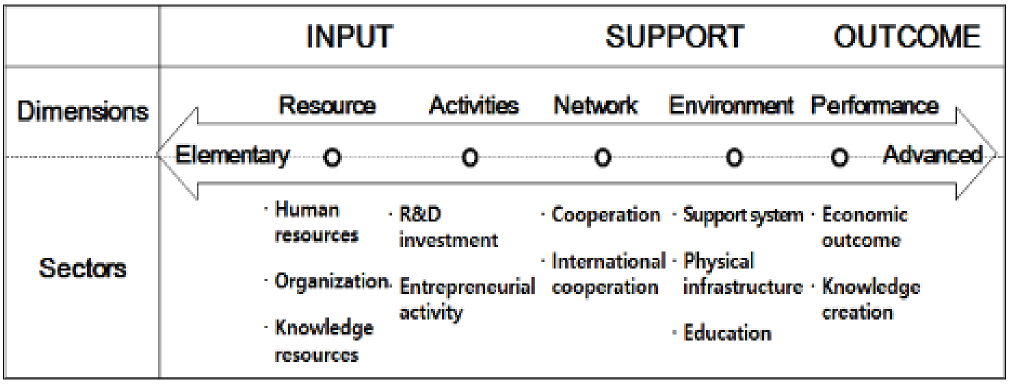

Fig. 1 COSTII framework

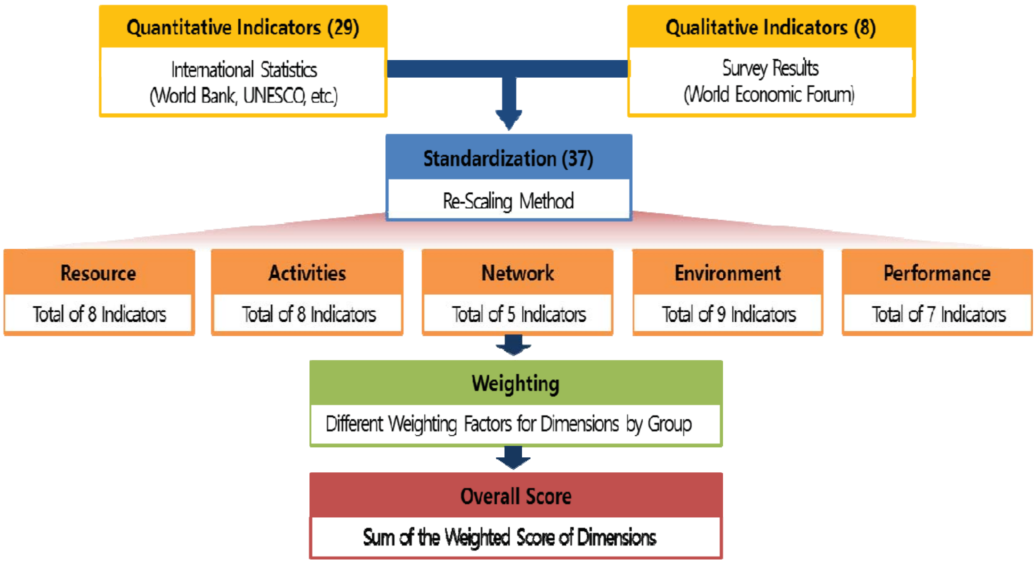

Fig. 2 Computation and structure of COSTII

IV. Results

1) Synthesis

The results of the analysis are shown in Fig. 3 and Table I.

2) Sectoral Characteristics

In the Resources dimension, among the human resources, organization, and knowledge resources sectors, Jordan ranked highest (0.84), followed by Iran (0.83) and Malaysia (0.80). In absolute terms, Malaysia did not have the highest total number of researchers compared to other countries, but its number of researchers per million were high, indicating a high concentration and quality of researchers, which are essential in securing the relevant human resources for innovation. In this respect, Malaysia was first (0.97), followed by Qatar (0.57) and Iran (0.43). Seven of the world's top 700 universities are located in Malaysia, and its quality of scientific research was rated 5.2, indicating healthy university and laboratory research standards. Meanwhile, Qatar and Iran both exhibited lower university research standards compare to laboratory standards, calling for efforts to improve innovation in post-secondary institutions.

Malaysia was also top in knowledge resources (0.75), with Iran at second (0.36) and Egypt at third (0.30). Malaysia exhibited high numbers of patents and dissertations, while Egypt was high in dissertations but low in patents and applications to WIPO.

In the Activities dimension, R&D investment was led by Qatar (1.0), Malaysia (0.7), Iran (0.69), Jordan (0.43), and the Dominican Republic (0.34). Qatar also had the highest entrepreneurial activity (0.74), followed by Costa Rica (0.55), Malaysia (0.52), Oman (0.52), and Uganda (0.43).

In the Network dimension, ranking over the three sectors was also led by Qatar (0.90), Malaysia (0.73), Jordan (0.41), Oman (0.410), and Costa Rica (0.39). However, the countries with the highest levels of international cooperation were Vietnam (0.78), Uganda (0.58), Egypt (0.51), Malaysia (0.50), and

Ethiopia (0.33). This variation is explained by differences in acceptance of foreign aid.

In the Environment dimension, rankings in national support systems are as follows: Qatar (0.50), Malaysia (0.83), Oman (0.58), Vietnam (0.50), and Jordan (0.48). The countries with the highest rankings for physical infrastructure were Qatar (0.83), Oman (0.75), Jordan (0.61), Malaysia (0.61), and Gambia (0.57). Quality of education was indicated by math and science education measures, with high performers being Qatar (1.00), Malaysia (0.9), Jordan (0.74), Iran (0.71), and Costa Rica (0.68).

In the Performance dimension, Malaysia (0.95), Costa Rica (0.65), Philippines (0.55), Iran (0.35), Jordan (0.27) exhibited better than average economic outcomes, while Qatar (0.77), Malaysia (0.57), Iran (0.38), Jordan (0.32), and Oman (0.22) ranked highly in knowledge creation.

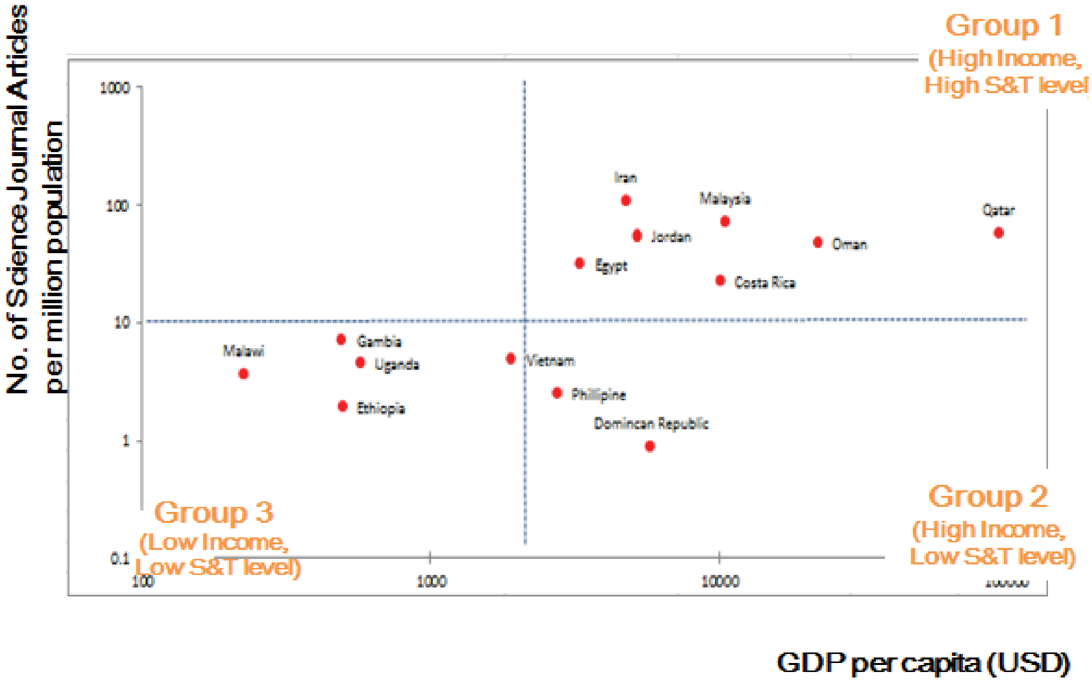

Fig. 3 Country groups, based on level of development

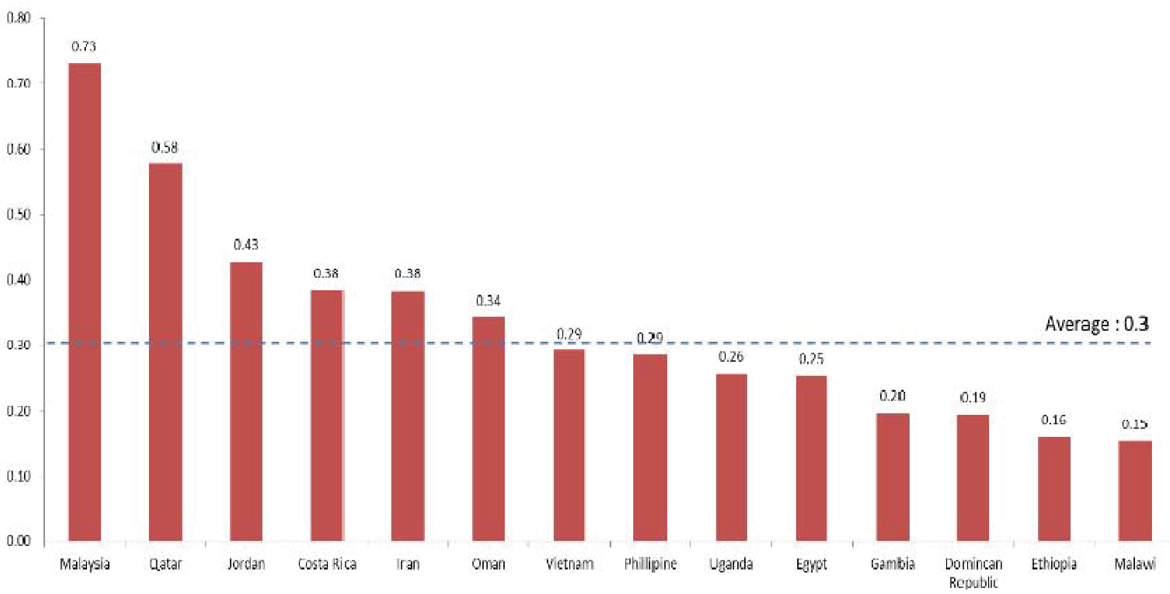

Fig. 4 Overall score

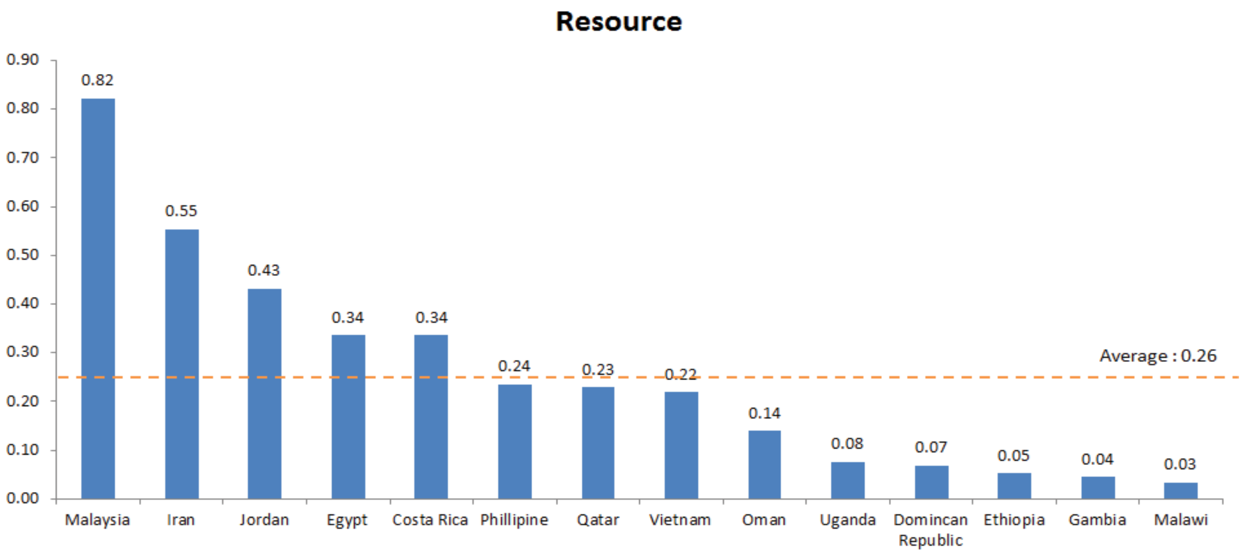

Fig. 5 Resources: scores of 14 countries

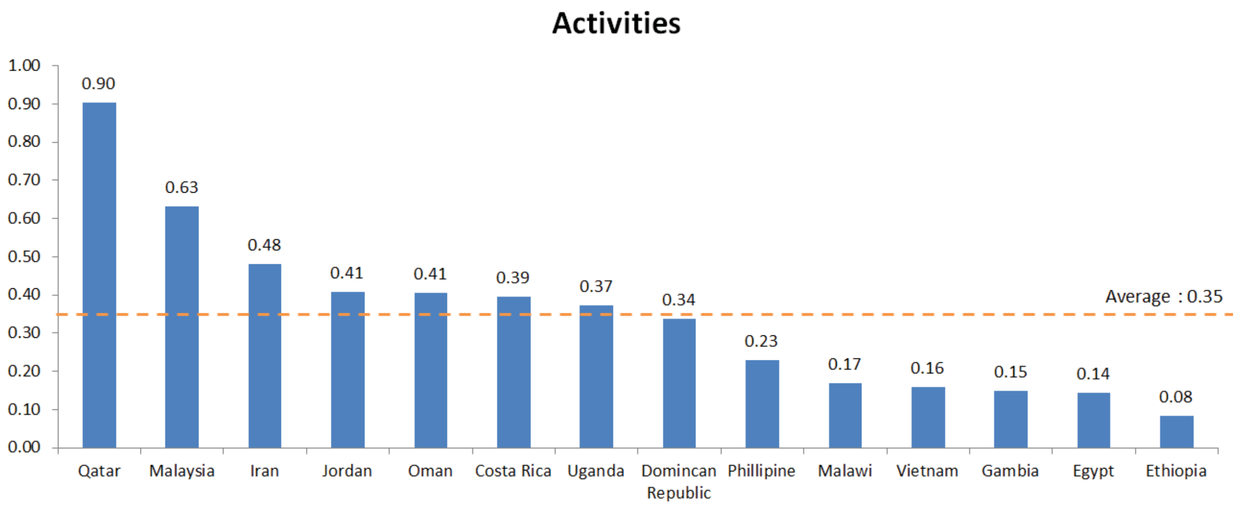

Fig. 6 Activities: scores of 14 countries

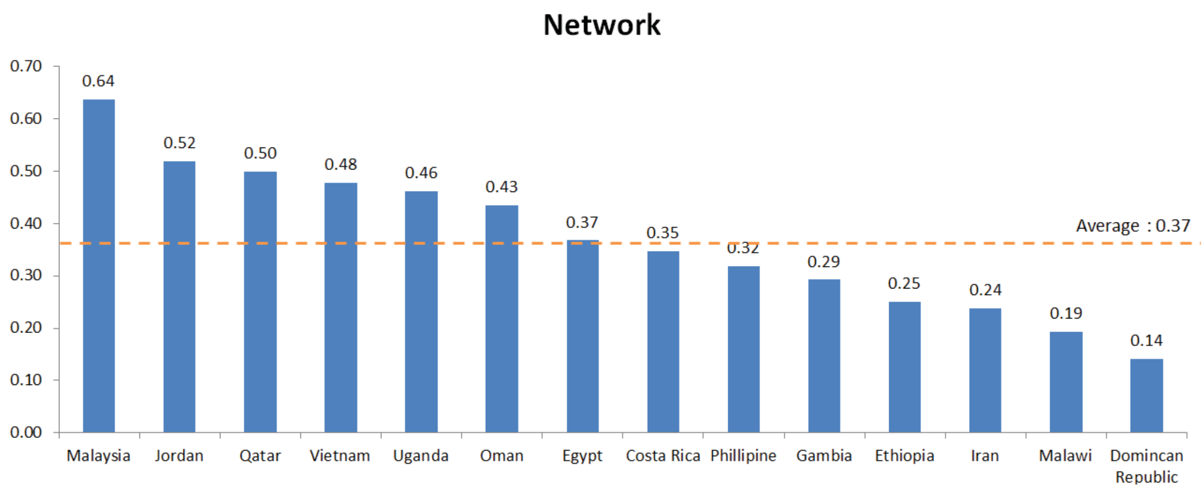

Fig. 7 Network: scores of 14 countries

TABLE I
ANALYSIS ON THE INNOVATIVE CAPACITIES OF 14 COUNTRIES

Dimension	Sector	Malaysia	Philippines	Vietnam	Gambia	Iran	Malawi	Oman	Qatar	Jordan	Ethiopia	Dominica Republic	Costa Rica	Egypt	Uganda
Resource	Human resource	0.80	0.23	0.44	0/02	0.83	0.01	0.20	0.21	0.84	0.05	0.07	0.57	0.5	0.06
	Ranking	3	7	6	13	2	14	9	8	1	12	10	4	5	11
	Organization	0.97	0.41	0.15	0.15	0.43	0.12	0.24	0.57	0.39	0.12	0.15	0.40	0.14	0.20
	Ranking	1	4	10	10	3	13	7	2	6	13	9	5	12	8
	Knowledge resources	0.75	0.13	0.04	0.00	0.36	0.00	0.02	0.02	0.04	0.01	0.01	0.05	0.30	0.01
	Ranking	1	4	6	14	2	13	9	8	7	10	12	5	3	11
	Average	0.82	0.24	0.22	0.04	0.55	0.03	0.14	0.23	0.43	0.05	0.07	0.34	0.34	0.08
Activities	R&D Investment	0.70	0.15	0.05	0.13	0.69	0.05	0.34	1.00	0.41	0.10	0.38	0.30	0.18	0.34
	Ranking	2	10	13	11	3	14	7	1	4	12	5	8	9	6
	Entrepreneurial activity	0.52	0.37	0.34	0.17	0.13	0.37	0.52	0.74	0.41	0.05	0.27	0.55	0.08	0.43
	Ranking	3	8	9	11	12	7	4	1	6	14	10	2	13	5
	Average	0.63	0.23	0.16	0.15	0.48	0.17	0.41	0.90	0.41	0.08	0.34	0.39	0.14	0.37
Network	Cooperation	0.73	0.39	0.27	0.37	0.19	0.27	0.59	0.83	0.72	0.20	0.10	0.43	0.27	0.38
	Ranking	2	6	9	8	13	10	4	1	3	12	14	5	11	7
	International Cooperation	0.50	0.22	0.78	0.17	0.31	0.08	0.20	0.00	0.21	0.33	0.20	0.22	0.51	0.58
	Ranking	4	8	1	12	6	13	10	14	9	5	11	7	3	2
	Average	0.64	0.32	0.48	0.29	0.24	0.19	0.43	0.50	0.52	0.25	0.14	0.35	0.37	0.46
Environment	Support system	0.83	0.33	0.50	0.23	0.22	0.16	0.58	0.91	0.44	0.40	0.27	0.36	0.13	0.06
	Ranking	2	8	4	10	11	12	3	1	5	6	9	7	13	14
	Physical Infrastructure	0.61	0.54	0.51	0.57	0.41	0.48	0.75	0.83	0.61	0.33	0.33	0.49	0.52	0.36
	Ranking	4	6	8	5	11	10	2	1	3	14	13	9	7	12
	Education	0.91	0.59	0.53	0.44	0.71	0.26	0.44	1.00	0.74	0.44	0.00	0.68	0.09	0.29
	Ranking	2	6	7	8	4	12	8	1	3	8	14	5	13	11
	Average	0.74	0.45	0.51	0.41	0.36	0.31	0.64	0.88	0.55	0.37	0.27	0.46	0.30	0.22
Performance	Economic outcome	0.95	0.55	0.17	0.07	0.35	0.02	0.07	0.00	0.27	0.05	0.26	0.65	0.19	0.18
	Ranking	1	3	9	11	4	13	10	14	5	12	6	2	7	8
	Knowledge creation	0.67	0.02	0.02	0.11	0.38	0.02	0.22	0.77	0.32	0.00	0.03	0.16	0.13	0.02
	Ranking	2	13	11	8	3	10	5	1	4	14	9	6	7	12
	Average	0.79	0.25	0.08	0.09	0.37	0.02	0.16	0.44	0.29	0.02	0.13	0.37	0.15	0.09

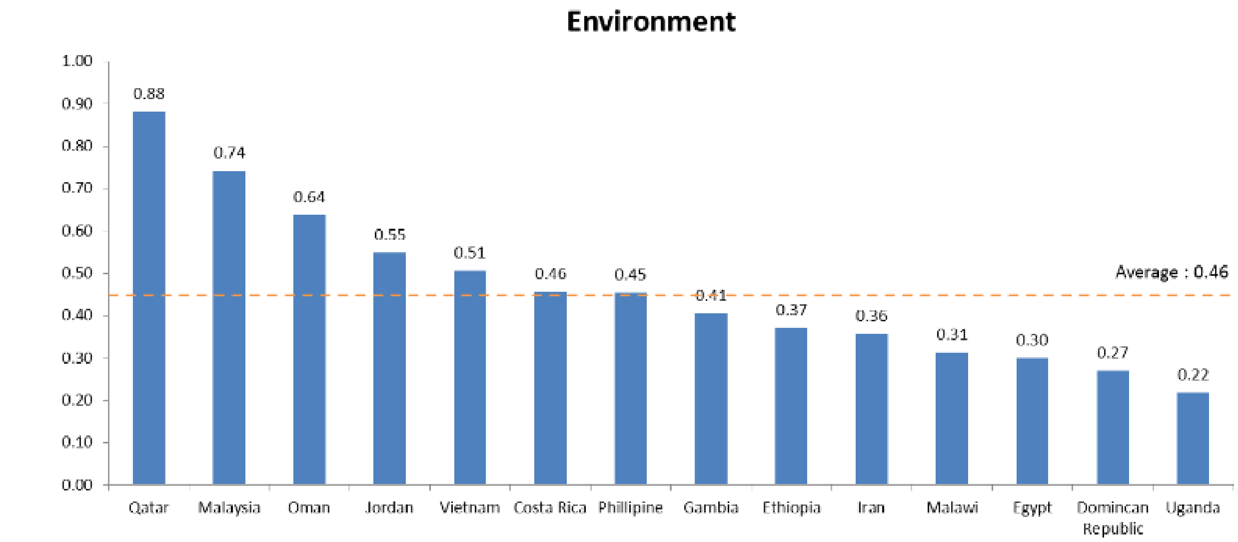

Fig. 8 Environment: scores of 14 countries

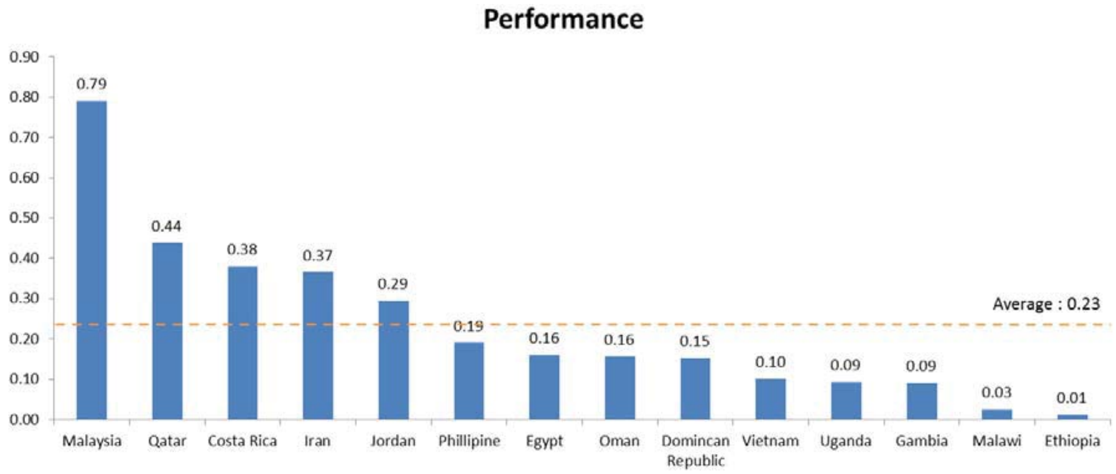

Fig. 9 Performance: scores of 14 countries

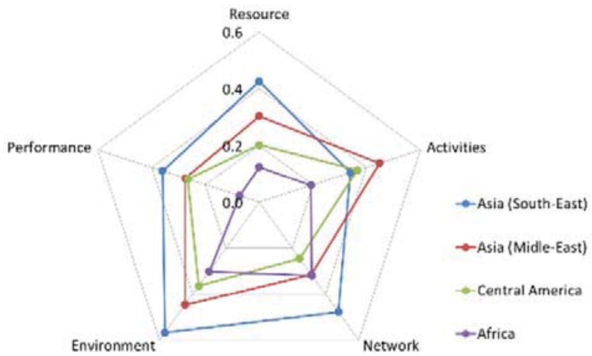

Fig. 10 Score of dimension by region

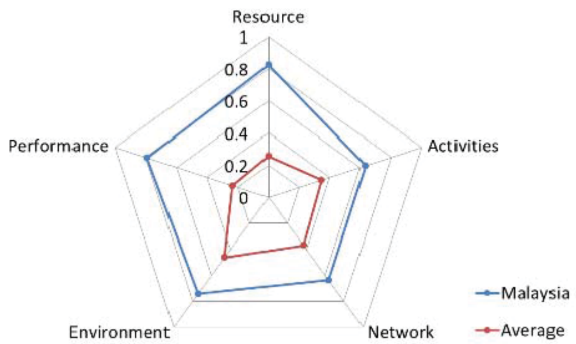

Fig. 11 Analysis of Malaysia

3) Characteristics by Country

Rankings of S&T innovative capacity by region was as follows: Southeast Asia, Middle East, Central America, and Africa. Asian countries all exhibited high rankings across categories when the Activities dimension was exempted, whereas Africa exhibited low indices in all areas. The indices for all countries are described below:

a) Asia: Malaysia ranked highly across all indices, notably possessing seven of 700 globally highest-ranked universities, and showed high levels in the Activities dimension. Its weaknesses were in its GERD ratio under the Network dimension, as well as its relatively high fixed broadband price, under the Environment dimension. The Philippines showed low results in all dimensions but Performance, especially R&D investment, and ranked 13th in patents, dissertations, and knowledge creation. Vietnam's strength was in foreign direct investments, but was weak in GERD and industrial technological capability.

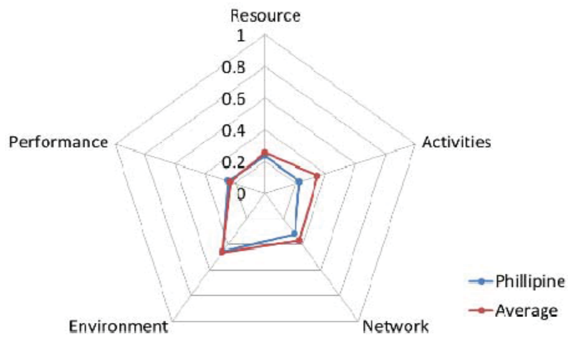

Fig. 12 Analysis of the Philippines

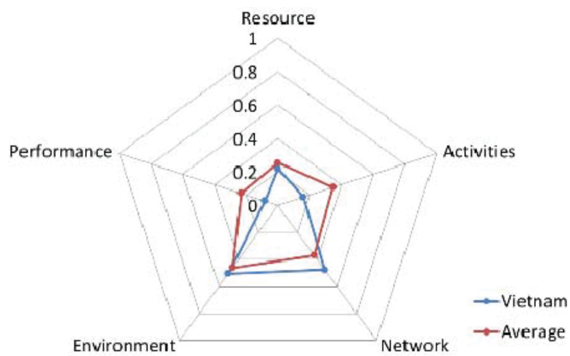

Fig. 13 Analysis of Vietnam

b) Middle East: Iran's Resources, Activities, and Economic outcomes ranked highly, while its Network, Environment and other indices suffered. Its strengths included its number of research labs under the Resource dimension, as well as its dissertations index. However, it was low in the joint ventures and strategic partnership indices in the Network dimension, and ranked 13th in cooperation. All indices for Jordan were observed to be higher than average, putting it in first place for human resources while its weakest area was in foreign direct investment. This was also a weakness for Oman, while its strength was in cell phone usage rates. Resources and Performance were its weakest dimensions, and Environment and Network were its strongest. Though Qatar ranked first in seven sectors, it showed the lowest outcomes in international cooperation and economic outcome sectors, and was below average in the Resources dimension. It exhibited strength in its industry technology adoption, university-industry relations, cost of Internet usage, and number of dissertations; Qatar was weak in joint ventures and high tech exports.

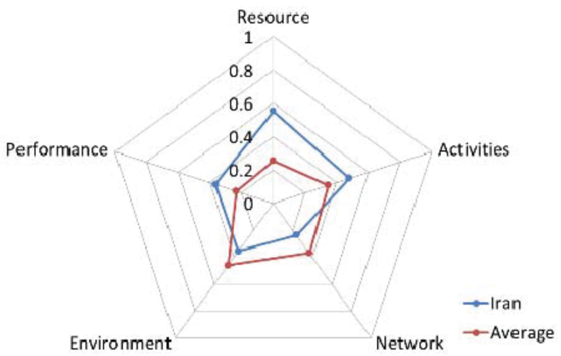

Fig. 14 Analysis of Iran

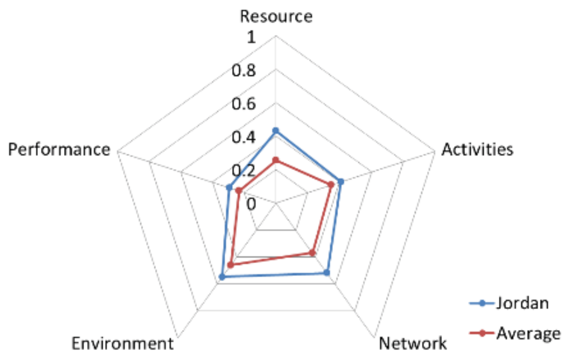

Fig. 15 Analysis of Jordan

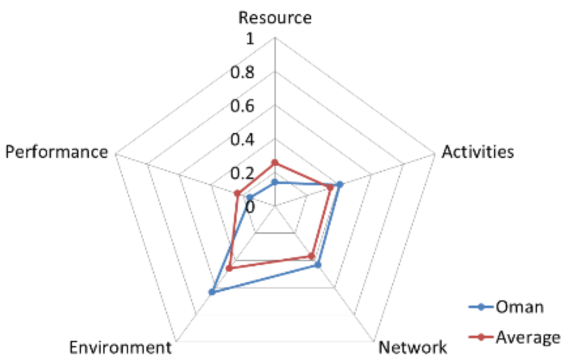

Fig. 16 Analysis of Oman

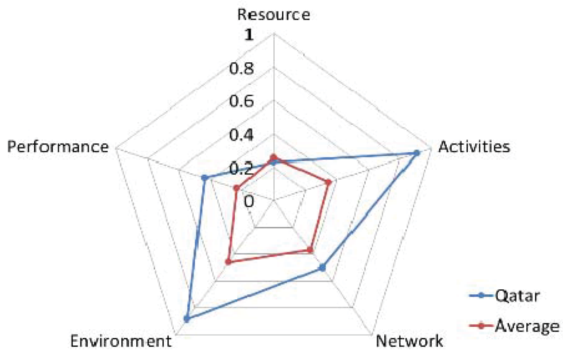

Fig. 17 Analysis of Qatar

c) Central America: Costa Rica ranked 4th overall, with high outcomes in Resources and Activities, low outcomes in Performance, and below average outcomes in Network and Environment. It was strong in the areas of new business density and gross value added per capita. Weaknesses were in joint ventures and strategic partnerships. The Dominican Republic was 12th overall, with weak outcomes in all dimensions except Activities. Its strength is in its new industry concentration, but does poorly in joint ventures and quality of math/science education.

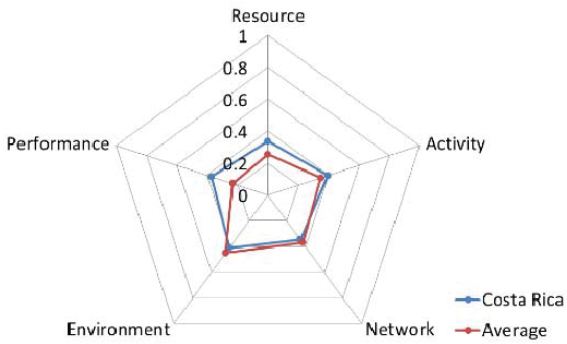

Fig. 18 Analysis of Costa Rica

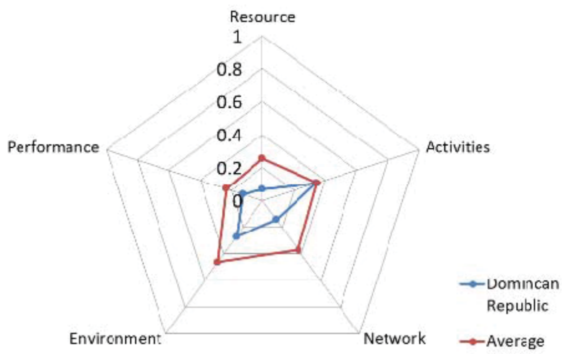

Fig. 19 Analysis of the Dominican Republic

d) Africa: Gambia ranked 11th overall and was lacking in all dimensions, particularly Resources. Cost of broadband was a strength, while the number of S&T dissertations was a weakness. Ranking 10th, Egypt's Resources were strong, and its Activities and Environment were weak. It had a high science dissertation number, but low concentration of new businesses and quality of math/science education. Ethiopia ranked 13th and performed poorest in human resources and organization—it had a high GERD ratio but low concentration of new businesses, Internet usage rate, and number of patents. With the lowest ranking of all sampled countries, Malawi was extremely weak in Resources and Performance, though it exhibited good startup activity and capability. Uganda, at 9th, showed competence in the Activity and Network dimensions but an insufficient Environment dimension. It ranked lowest in the support systems sector and 12th in physical infrastructure. Although it had high foreign GERD, national intellectual property protection was poor.

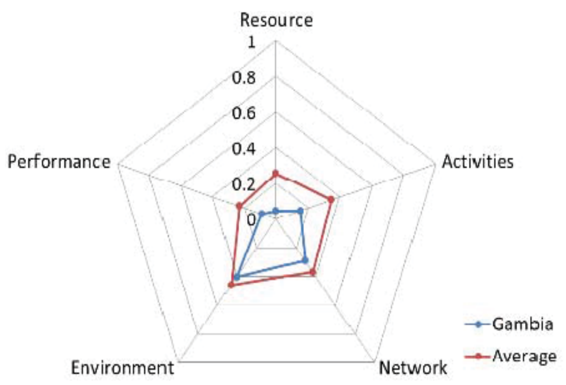

Fig. 20 Analysis of Gambia

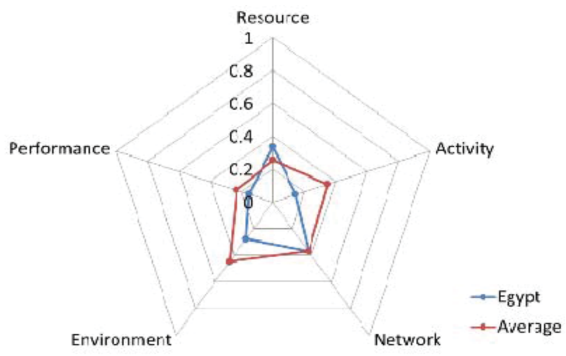

Fig. 21 Analysis of Egypt

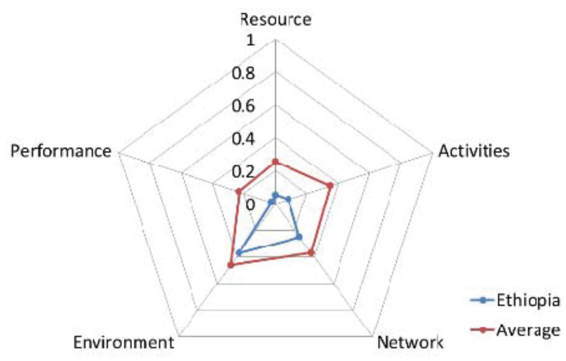

Fig. 22 Analysis of Ethiopia

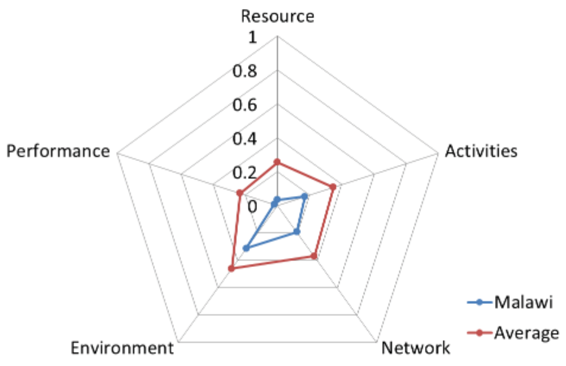

Fig. 23 Analysis of Malawi

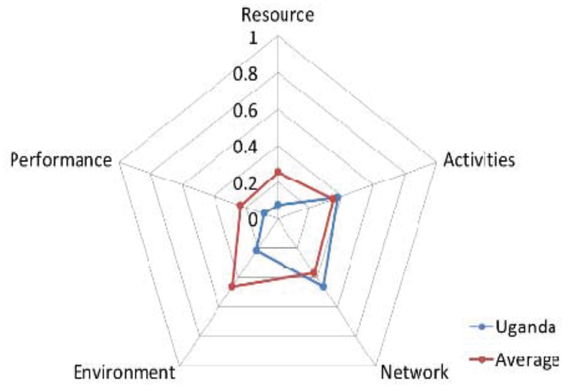

Fig. 24 Analysis of Uganda

V. Conclusion

This study aimed to provide basic evidence for improving S&T innovative capacity as a way to improve national competitiveness. In summary, the Middle East and Southeast Asia show relatively high potential for expanding S&T innovative capacity. Central American countries show a large gap in potential, and though African countries are generally lacking in many sectors, Egypt and Uganda also has potential for development.

Each country has been shown to face distinct challenges and therefore would be hard-pressed to achieve growth by attempting to replicate the trajectories of current developed countries. Some customization is necessary to implement policies that best address a country's individual setbacks. Sagasti asserted that, to be effective, efforts to construct an S&T infrastructure must be accompanied by a comprehensive development strategy [13]. For many developing nations, economic industries remain weaker than actual S&T capabilities, and relevant regulatory authorities may not exist. Using input-support-output classifications of the current framework, we analyze national priorities of the examined countries as follows:

a) In both the Philippines and Vietnam, input is lacking, and output is also weak or unstable. Creative accumulation receives insufficient support, and requires more active R&D investment and active cooperation between key players.
b) Iran exemplifies successful conversion of inputs into

useful outputs. Qatar shows high deviation across three dimensions, and requires further improvements in joint ventures and other sectors in the Network dimension. Jordan has achieved more equal levels of development in three dimensions, but needs to address its Network dimension as well. Oman lacks both input and output, thus requiring Network support to bridge the gaps.

c) Costa Rica also has sufficient inputs and outputs, but requires stronger support systems. The Dominican Republic overall performed weakly and needs greater cooperation and improvements to education to support an environment that fosters innovation.

d) Within Africa, most countries possessed few inputs and consequently produced low outputs. Gambia would benefit from human resources development, whereas Egypt is recommended to advance its STEM education and create policies to encourage new businesses. Ethiopia and Malawi should prioritize the support of human resources and capital to enhance its inputs. Uganda exhibits satisfactory inputs and support, but lags in performance. Support systems therefore should be a strong priority.

Though with similar GDPs, Malaysia, Uganda, Qatar, Oman, and Costa Rica, respectively, possess differing potentials. Results from using the current indices demonstrated that support to Resources and Activities for developing countries is probably far more important than Performance support is to slightly more developed countries. Southeast Asia in particular has potential to reap disproportionately large benefits from improvements to its Activities dimension. The current study uses Lundvall’s concept of national systems of innovation, as well as important indicators to identify areas that urgently need advancing. This investigation into the S&T innovation capacities of the developing countries will hopefully serve as a future reference to relieving their alienation from developed countries in matters of science and technology.

APPENDIX

TABLE II
COMPOSITION OF INDICATORS

Dimension	Sector	Indicator	Source
Resource	Human resources	Total researchers (FTE)	UNESCO
		Total researchers per million population (FTE)	UNESCO
		Gross enrolment ratio, tertiary, both sexes (%)	UNESCO
	Organization	Number of universities ranked in the world's top 700 universities (2014)	QS World University Ranking 2014
		Quality of scientific research institutions*	WEF
	Knowledge resources	Scientific and technical journal articles in the past 15 years ('97~'11)	World Bank
		Number of USPTO patent grants since 2000	USPTO
		Number of international applications via WIPO-administered treaties (PCT System) since 2000	WIPO
Activities	R&D investment	GERD	UNESCO
		GERD as a percentage of GDP	UNESCO
		GERD per researcher, FTE	UNESCO
		Firm-level technology absorption*	WEF
		GERD financed by government of GDP (%)	UNESCO
	Entrepreneurial activity	Total early-stage entrepreneurial activity (TEA)	GEM2013 Global Report
		New business density (new registrations per 1,000 people aged 15-64)	World Bank
		Venture capital availability*	WEF
Network	Cooperation	State of cluster development*	WEF
		University-industry collaboration in R&D*	WEF
		Number of joint venture/strategic alliance deals	INSEAD Global Innovation Index 2014
	International cooperation	GERD financed by abroad (%)	UNESCO
		Foreign direct investment, net inflows	World Bank
Environment	Support system	Intellectual property protection*	WEF
		CPIA transparency, accountability, and corruption in the public sector rating	World Bank
		Government procurement of advanced technology products*	WEF
		Ease of doing business index	World Bank
	Physical infrastructure	Fixed (wired) broadband subscriptions per 100 inhabitants	ITU
		Mobile-cellular telephone subscriptions per 100 inhabitants	ITU
		Percentage of individuals using the internet	ITU
		Fixed broadband price	ITU
	Education	Quality of math and science education*	WEF
Performance	Economic outcome	Gross value added at factor cost per capita	World Bank
		High-technology exports (% of manufactured exports)	World Bank
		Charges for the use of intellectual property per million population (receipts)	World Bank
	Knowledge creation	Number of USPTO patent grants per million population	USPTO
		Number of international applications via WIPO-administered treaties (PCT) per million population	WIPO
		Scientific and technical journal articles per million population	World Bank
		Citations per million population	SCImago Journal & Country Rank

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