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Research Article

A Diagnostic Toolkit for Innovation Systems in Developing Countries: An Analysis of Selected ASEAN Countries

Dong Un Park[1,*], Taehyun Jung[2], Wan Seok Chang[3], Youngjin Kim[4], Fernando Santiago Rodriguez[5]

[1]Science and Technology Policy Institute, Sejong, REPUBLIC OF KOREA.
[2]Hanyang University, Seoul, REPUBLIC OF KOREA.
[3]Economic Research Institute for ASEAN and East Asia, Jakarta, INDONESIA.
[4]George Mason University, Virginia, USA.
[5]United Nations Industrial Development Organisation, Vienna, AUSTRIA.

ABSTRACT
This study develops a diagnostic toolkit designed to evaluate innovation systems in developing nations, featuring 17 indicators across six categories based on national innovation systems theories and the system failure framework, with a focus on reflexivity and demand articulation issues. The toolkit was tested in three ASEAN countries—Cambodia, Indonesia, and Thailand—using China and Korea as benchmarks. Its innovative approach lies in offering benchmarks and targets through comparisons with peer countries' positions and outlining potential pathways. The research utilizes a heatmap dashboard to contrast the innovation performance of each country against the average of its income group, integrating these findings into a country gap profile. This profile aids in crafting innovation policy recommendations tailored to a country's specific developmental needs and innovation system characteristics. The study significantly contributes to scientometric literature by introducing a practical, theory-based indicator system for innovation policy aimed at developing countries and enhances understanding of national innovation systems, particularly in the under-researched ASEAN context.

Keywords: ASEAN, Developing Country, Indicator, Innovation Policy, National Innovation Systems, Systems Failure Framework.

Correspondence:
Taehyun Jung
Hanyang University, Seoul,
REPUBLIC OF KOREA.
Email: tjung@hanyang.ac.kr

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INTRODUCTION

Industrial and innovation policies are fundamental for economic development and industrial progress.[1-3] rafting and implementing customized industrial innovation policies that align with a country's economic development stage and innovation system characteristics are essential but challenging tasks. These challenges are particularly acute in developing countries, where a lack of tools and capabilities often hampers the identification of their national innovation system's characteristics and the enactment of tailored policies.[4,5] Relying on the direct adoption of policies from advanced nations or the exclusive focus on labor-intensive industries has proven ineffective.

The initial step in developing these capabilities must involve diagnosing the current status in the domains of innovation and industry policy.[6,7] Unfortunately, existing indicator systems designed for this purpose are often ill-suited for developing countries, primarily due to issues such as data unavailability or, when available, a lack of comprehensive theoretical grounding to guide policymakers in formulating a cohesive set of policies.[4] Alternatively, even in the absence of theoretical underpinnings, drawing the appropriate next steps and associated pathways is possible if provided with proper benchmarks and heuristics, which are rarely integrated into existing indicator systems. A robust indicator system for innovation policies in developing countries must address these additional challenges in addition to meeting conventional criteria for effective indicators.

This research introduces a diagnostic toolkit that specifically addresses these challenges, tailored for assessing innovation systems in developing countries. It encompasses 17 key indicators across 6 categories, all grounded in the theories of national innovation systems and the system failure framework, with a particular emphasis on failures related to reflexivity and demand articulation. In the context of developing countries, obtaining even basic statistics on R&D and innovation is often a challenging task. To surmount this obstacle, we conducted a thorough assessment of data availability and other attributes (such as quality, representativeness, and the relevance to the theoretical concepts) for each of hundreds of potential indicators across the six categories, encompassing not only the ASEAN region but also countries in Africa, the Middle East, and Latin America.

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Subsequently, the toolkit is applied to three ASEAN countries—Cambodia, Indonesia, and Thailand—with China and Korea serving as benchmarks. Even with a comprehensive set of indicators, policymakers often find themselves uncertain about the next steps to take. Imitating the strategies of advanced countries is not always the optimal approach. A more critical consideration is gaining a deeper understanding of the positions of peer nations and identifying immediate next steps. The novelty of this research lies in its provision of benchmarks and targets by simultaneously illustrating the positions of peer countries (i.e., those within the same income group) and the associated pathways.

To achieve this, the research presents the levels and changing rates of four income groups (high income, upper-middle income, lower-middle income, and low income) for each indicator. Furthermore, the performance of the focal country is compared to the average performance of the corresponding income group and presented in the form of a *heatmap dashboard*. This research amalgamates the results of pathway analysis and heatmap dashboard into a country gap profile for the focal country, allowing for the formulation of innovation policy recommendations that align with its developmental stage and the characteristics of its national innovation system.

We selected three ASEAN countries from each income group: Thailand from the upper-middle income, Indonesia from the lower-middle income, and Cambodia from the low-income group. Korea belongs to the high-income group, while China is in the upper-middle income group. This set of observations is expected to illustrate the utility and versatility of the suggested indicator systems, as well as provide insights into common policy issues faced by selected ASEAN countries.

This research contributes to the scientometric literature by offering a theory-inspired yet practical indicator system for innovation policy, tailored specifically to developing countries. It also enriches the literature on national innovation systems by providing a comprehensive assessment of the rarely studied less developed countries, with a focus on the ASEAN region.

INNOVATION SYSTEMS, INDICATORS, AND DEVELOPING COUNTRIES

In this section, we provide a brief review of the literature on innovation systems and indicators in the context of developing countries. We do not aim to conduct a comprehensive review of all relevant literature, as the primary objective of this paper is not to make theoretical distinctions between innovation systems or indicators in developing and developed countries. Instead, our focus is on presenting a set of practical indicators that policymakers in developing countries can use to assess the strengths and weaknesses of their innovation systems. Therefore, the goal of the review presented below is to contextualize the diagnostic toolkit of innovation indicators we offer and to clarify our contribution.

The literature clearly indicates that the technological and industrial capabilities required for advancing economic development vary across different stages of economic development. For example, as a country progresses along its development path, it transitions from sourcing and combining factors for production to acquiring novel ideas and technologies.[8] It also shifts from labor-intensive to capital-intensive production techniques,[9] and from technology imitation to assimilation and new development capabilities.[10] Therefore, an indicator system for innovation that is suited to developing countries should encompass not only factors related to technological novelty but also elements related to production systems.

Another issue to consider regarding innovation indicators for developing countries is their poor data availability. Many indicators commonly available in advanced countries, such as R&D personnel or innovation activities in the private and public sectors, are not collected in most developing countries due to the low utility of these indicators for immediate policy needs or simply inadequate statistical capabilities. Consequently, we cannot use most indicators from the rich datasets such as the Science and Engineering Indicators provided by the National Science Foundation in the United States or the Main Science and Technology Indicators provided by the OECD.

One way to overcome the data availability issue is to rely on a limited set of available indicators, resorting to bibliometric data or internationally collected data. Another approach is to build a custom, high-cost dataset, primarily based on international surveys, as the World Economic Forum does for the Global Competitiveness Index or the IMD Business School in Switzerland does for the World Competitiveness Ranking. However, these methods are limited in their country coverage and often criticized for their representativeness. Therefore, we adopt the former methods in this paper.

The set of indicators proposed by Archibugi and Coco[11] and the Global Innovation Index[12] already satisfy the two conditions we suggested above. The Archibugi-Coco(or ArCo) index includes seven indicators–patents, scientific articles, Internet penetration, telephone penetration, electricity consumption, tertiary science and engineering enrolment, mean years of schooling, literacy rate–across three main dimensions: the creation of technology, the technological infrastructures, and the development of human skills. The Global Innovation Index (GII) includes 80 indicators across four categories: science and innovation investment, technological progress, technology adoption, and socioeconomic impact, covering 132 countries in its 2023 version.

The issues with these indicator systems for policymakers in developing countries are two-fold, as we argue. First, the number of indicators is either too small (7 for the ArCo) or too large (80 for

GII). The ArCo index does not address institutions or networks, which are regarded as crucial components of any innovation system. One may ask why a large number of indicators is an issue. While the flexibility and utility of the GII for researchers are immense, policymakers in developing countries are generally not experts in indicators nor enthusiasts in analyzing broad policy issues. Therefore, it is commendable to provide them with a manageable number of indicators. It is similar to the need for parsimony in models, ensuring they convey a sufficient level of information without becoming overwhelming. So, how can we ensure that a system of indicators conveys a sufficient level of information? This relates to the second issue we discuss below.

Second, both the ArCo and GII need improvements in their models. Theoretical models of an indicator system play at least three roles: first, to provide a framework for testing the construct validity of individual indicators and the system as a whole; second, to organize indicators so users can readily understand the overall picture and structural relationships; and third, to help users link and interpret the models for practical policy issues. Against these roles, the ArCo index lacks important components of innovation systems, such as institutions and networks, thus failing to fulfill the framework and organizer roles. The GII categories, on the other hand, are based on an input, activity, output, and outcome continuum of innovation, instead of being organized using the structural relationships of innovation systems, which leads the GII to fall short of providing insights into innovation systems or practical policy implications.

To address the weaknesses in both indicator systems, we based our indicators on the widely accepted understanding of innovation systems. The Systems of Innovation (SI) approach has been proposed and developed collectively by many prominent scholars in innovation studies. The SI approach was first conceptualized to explain the heterogeneity in countries' innovation processes and performances.[13-15] Furthermore, innovation systems cover all processes that determine innovation[6] including the elements related to production systems as well as technological novelty, thus satisfying the first condition we discussed above. The policy relevance and usefulness of the SI approach have already been demonstrated in numerous studies,[16-20] to list only a few. Additionally, innovation scholars largely agree that the SI

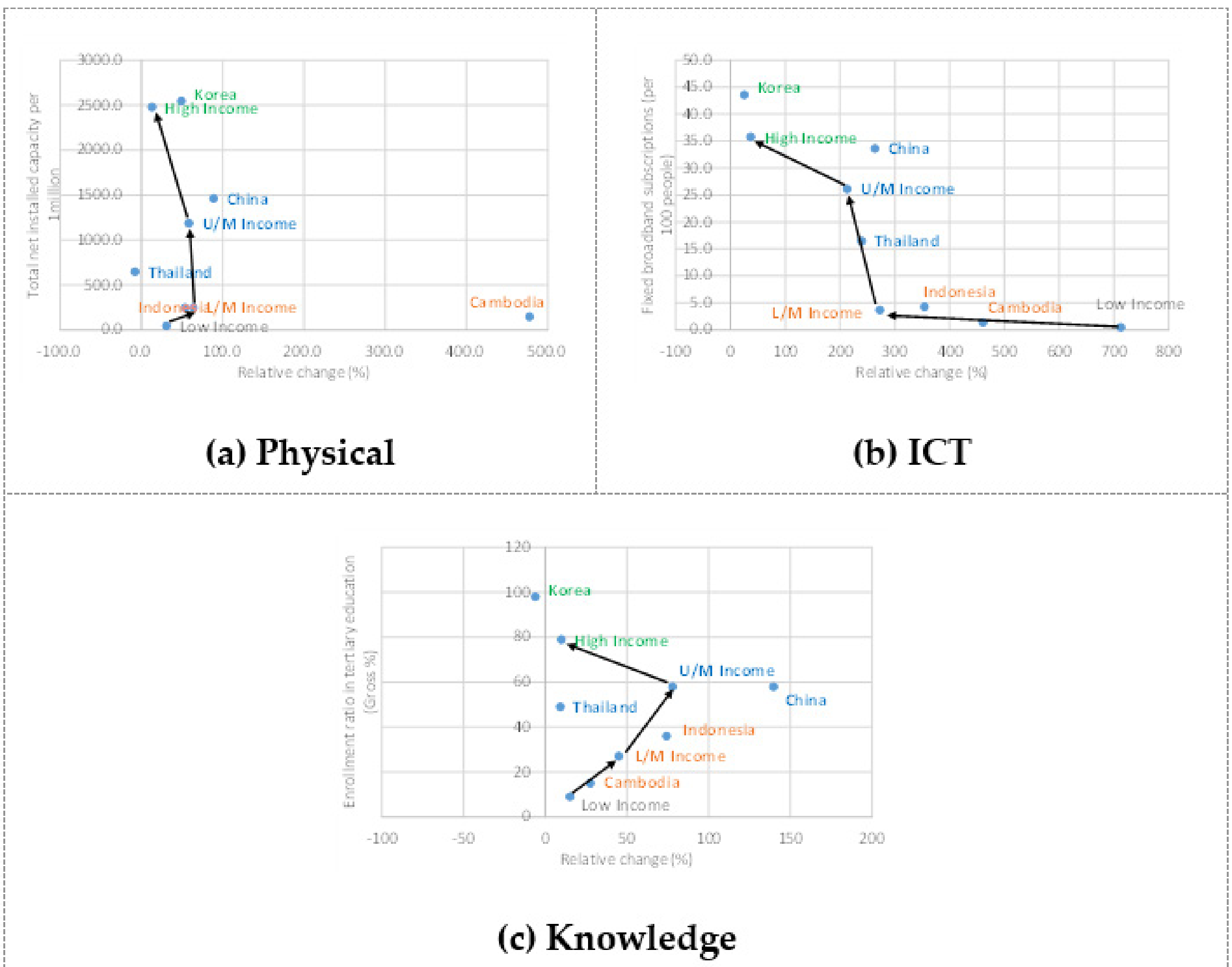


Figure 1: Pathway, changes and levels for infrastructure

Table 1: Structure of the indicator system

System component			Indicator
Level 1	**Level 2**	**Level 3**	
Reflexivity	Infrastructure	Physical	Electricity generation installed capacity (kW) per 1 million people.
		ICT	Fixed broadband subscriptions per 100 people.
		Knowledge	Enrollment ratio in tertiary education.
	Institution	R&D investment	Expenditure on R&D as % of GDP.
		Innovation attractiveness	Patents by non-residents, per million people.
		New business creation	New business registration per 1,000 people ages 15-64.
		Market financing	Market capitalization of listed domestic companies, % of GDP.
	Interaction (network)	Production	Share of firms exporting directly/indirectly (at least 10% of sales).
		Technology	Intellectual property payments per GDP (current US$ millions).
		Science	International co-authored scientific articles per 100,000 people.
	Actors and capabilities	Production (capacity)	Gross fixed capital formation as % of GDP.
		Production (quality)	ISO 9001 certificates per 10 million people.
		Technology	Patents by residents, per million people.
		Science	Scientific and technical articles, per million people.
Demand articulation	Public sector		Public procurement as % of GDP.
	Private (domestic) sector		ICT imports as a share of total imports.
	Private (foreign) sector		Medium/high-tech exports as a share of total manufactured exports.

Source: Authors' elaboration.

approach reflects the innovation mechanisms and outputs more realistically than alternative explanations, such as the neoclassical theory of technological change.[21,22]

The conceptualization of innovation systems has varied and evolved to address different levels and boundaries of systems such as nations, regions, sectors, technologies, or socio-technical regimes. It has also focused on different aspects of the model, such as structural relationships, particular components, functions, or dynamics.[19,23,24] However, the three structural components of innovation systems are almost invariably actors, networks, and institutions, regardless of the variations in theories. Additionally, the economic and knowledge infrastructure of a system of interest is another necessary component across different theoretical models. Therefore, we regard these four components—i.e., infrastructure, institutions, networks, and actors—as essential for comprehensively depicting an innovation system from a structural viewpoint.

However, this perspective is not without criticisms. Recent discussions of innovation systems point out systems transitions,[18,25] dynamic systems failures,[19,20] and the directions and potential for a transformative change.[23] We incorporate these aspects into the model by including demand articulation capabilities from the systems failure framework.[19,20] In the next section, we provide a detailed account of the developed model and indicators.

A DIAGNOSTIC TOOLKIT FOR INNOVATION SYSTEMS

A proper set of indicators helps policymakers identify systemic problems in their STI systems as well as articulate demands for innovation. In line with the idea of evidence-based policymaking, the indicator system proposed here aims to provide a foundational element of evidence-based policy-making, which remains absent or suboptimal in the case of many developing countries. There are widely used indicator systems in STI, such as the Science and Engineering Indicators from the United States' NSF,[26] the Main Science and Technology Indicators from the OECD, European Innovation Scoreboard (EIS) by the European Commission, and the Global Innovation Index from WIPO,[12] to name just a few. These systems use well over hundreds of STI indicators, many of which, however, are often not available or do not fit the context of developing countries as we discussed above.

To identify indicators that are generally available for most developing countries and, at the same time, are sufficiently informative of the developing country context, we apply three selection principles. First, indicators must be *publicly available* for a wide range of countries, including developing countries. Second, indicators should be *relevant* to STI and industrial policy, especially for developing countries. Third, if there are similar but somewhat different indicators that satisfy the first and the second principles, the selected indicator should be *representative and simple* enough for policymakers to readily understand its linkage to the real world.

The structure of our indicator system is presented in Table 1, and following Figure 1, begins with *reflexivity* and *demand articulation* as the two top-level components. Reflexivity is then broken down into the four pillars of innovation systems discussed in section 2: infrastructure, institutions, networks, and actors and capabilities. For demand articulation, most of the questions posed in Box 3 are not generally answerable using quantifiable statistics, especially for developing countries. Thus, we focus on three aspects: 1) the roles of the public sector, particularly as a consumer of innovation, including through strategic procurement of innovation; 2) the relative size of the digital industry in the import market; and 3) the relative size of sophisticated industries in the export market. Both 2 and 3 are used as a proxy for a government's intended policy efforts to promote industrially upgraded products in its domestic and exporting markets.

Reflexivity features a third level, which includes infrastructure that can be broken down into: 1) Physical infrastructure, 2) Information and Communication Technology (ICT) infrastructure, and 3) Knowledge infrastructure. Physical infrastructure that is important for STI and industry development encompasses many things, such as transportation and logistics, residential and dwelling, city infrastructure, energy generation and distribution, and so on. Here we only focus on energy generation for two reasons: 1) it is essential for industrial development in the modern era, and 2) data availability. ICT infrastructure is another critical enabler for modern industries and STI capabilities. Knowledge infrastructure is important because innovative capabilities are cumulative and embedded with human capital (here, we use a generic level of human capital as a proxy for knowledge infrastructure[1,2]).

Institutions, which cover rules, regulations and laws that may affect innovation and industrial development processes and

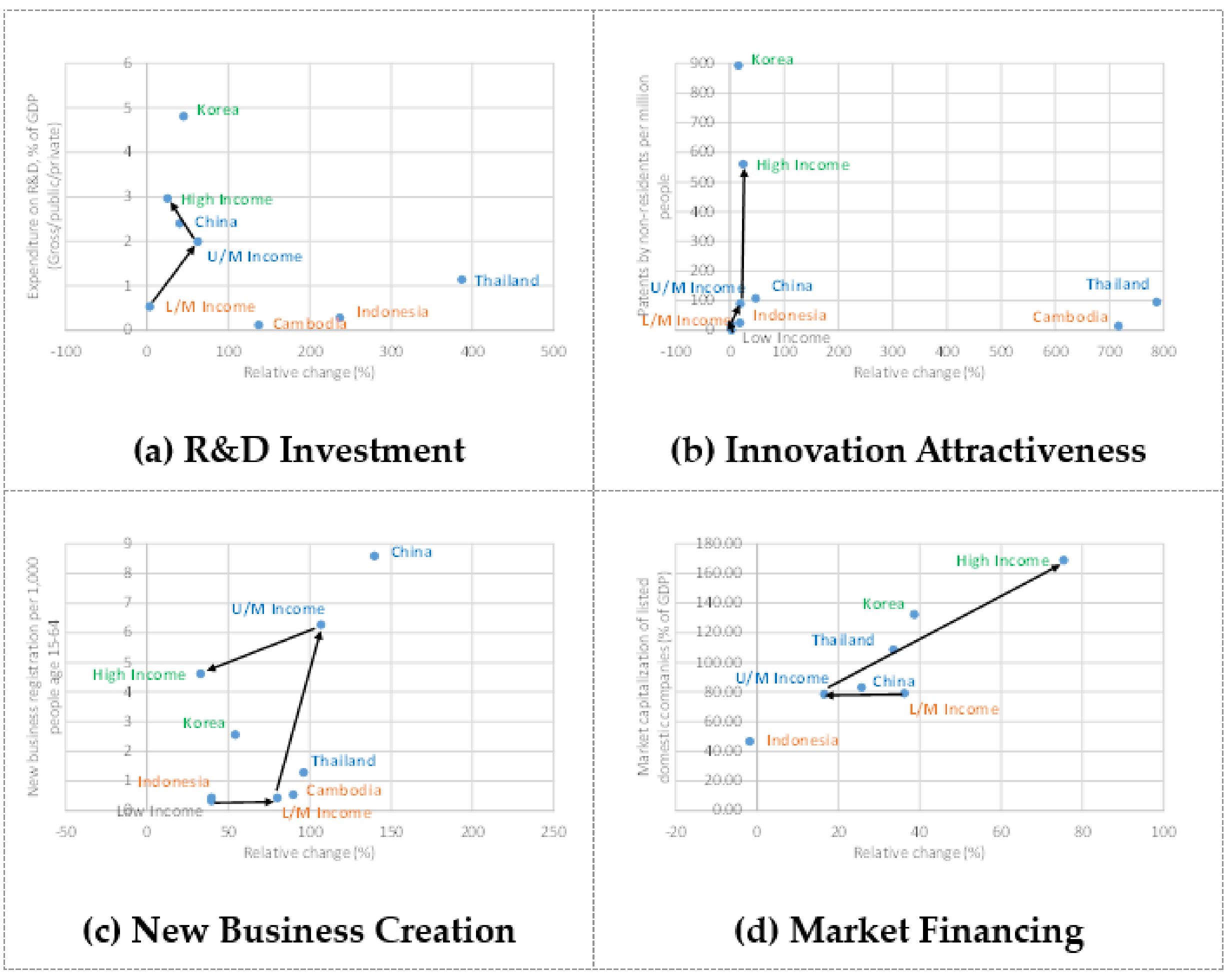


Figure 2: Pathway, changes and levels for institution. Note: Data for low income group is not available for panel (a) and (d)

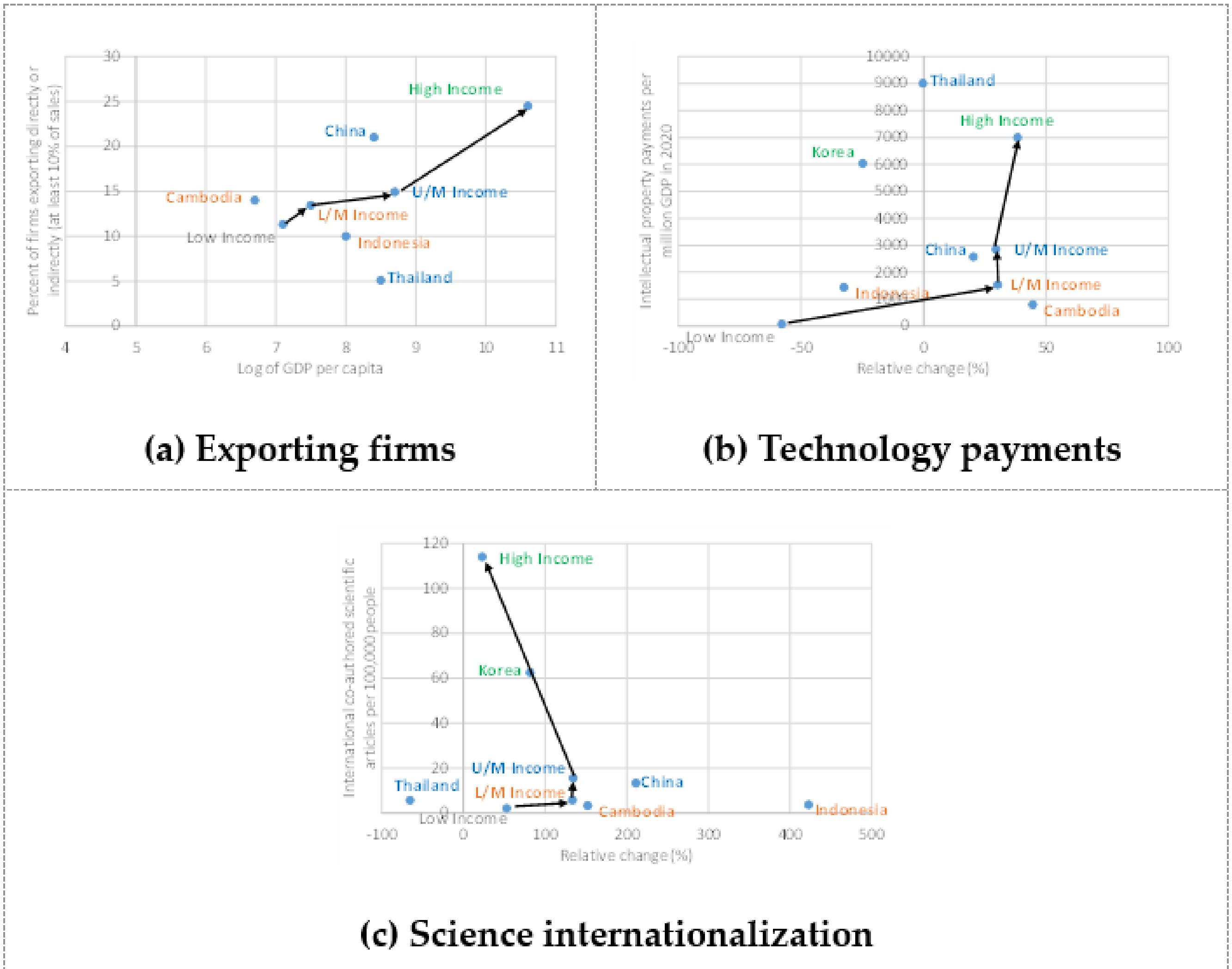


Figure 3: Pathway, changes and levels for interaction. Note: Data of Korea is not available for panel (a)

outcomes. They may guide resource allocation and actions of the participants while often affecting the level and distribution of outputs from innovation and industrial development. Despite their importance, it is hard to see institutions as indicators because they are not homogeneous across different countries nor readily quantifiable. A particular policy or law of a country is subject to the specific socioeconomic context of the country. Therefore, indicators for institutions are generally indirect and selective. Here, we focus on three areas of institutions: 1) gross R&D investment, 2) intellectual property protection, 3) entrepreneurial activities, and 4) financial investment.

R&D investment is one of the most critical measures indicating an innovation system's general strength and performance. Without a package of sound R&D-supporting institutions, a sizable investment in R&D from the public or private sector may not be possible. Hence, the size of R&D investment should collectively and indirectly indicate the effectiveness of R&D-supporting institutions (e.g. R&D tax credits, the conventions for government R&D appropriations, and policies for direct and indirect R&D performing institutes, among others). Hence, investment in R&D is proposed as the first category of institutions.

It is well known that intellectual property protection is crucial for innovators to be able to benefit from their own innovations.[27] Hence, this tool includes an indicator for measuring Innovation attractiveness.[3] Similarly, the tool adopts a measure for the degree of entrepreneurial activities because a number of new businesses are crucial for turning innovations into industrial

1 Measures of knowledge stock that calculate a cumulative number of patents or scientific articles are also used for this purpose. However, we believe human capital has more profound policy implications than knowledge stock, especially in the early stage of developing countries, because their knowledge stock has not yet accumulated and should be embedded with human capital.

2 "Gross graduation ratio" is a better indicator for our purpose. However, due to data limitation, we did not adopt it as an indicator. For the indicator, we have around 75 countries' data available, and only 34 possible for historical analysis (five of our 15 example countries) from the UNESCO database (http://data.uis.unesco.org/).

3 We admit the limitations of patenting activities as measurements of innovation activities in that 1) not all innovations are patented, and 2) patenting becomes more pronounced from the upper-middle-income (UMI) stage, as shown in our analysis in Section 4. Still, level of patenting activities is generally believed to be a useful indicator for this purpose.

performances.[28] Finally, we included an indicator to measure the overall strength of financing with the level of domestic financial investment.

The network component breaks down into international and domestic networks. While domestic networks such as public-private partnerships, industry-university collaboration, and innovation clusters are crucial in STI and industry capability development, their indicators are not readily available in developing countries. Imported technology and foreign direct investment play a crucial role in the early stage of industrial development.[29] We can measure international linkages of scientific collaboration and technology trades relatively directly and capital-embedded knowledge exchange indirectly through the degree of global value-chain participation. Hence, our network components deal with international networks in production, technology, and science, respectively.

Similarly, actors and capabilities focus on three sub-units: 1) production capability, 2) technological capability, and 3) scientific capability. These three units are roughly consistent with the main actors of innovation as discussed in the literature on triple helix[30] or innovation systems.[31] We have not explicitly dealt with learning capability (such as the mode or speed of learning) or monitoring capability (as realized in the public or private think-tanks) because their indicator values are, unfortunately, not generally available.

We presented country coverage and data sources for each indicator in Tables 2 and 3. For further details of the indicators and methodology, please refer to the following UNIDO report.[4]

ANALYTICS AND VISUALIZATION

We selected three ASEAN countries from each income group: Thailand from the upper-middle income, Indonesia from the lower-middle income, and Cambodia from the low-income group. Korea belongs to the high-income group, while China is in the upper-middle income group. This set of observations is expected to illustrate the utility and versatility of the suggested indicator systems, as well as provide insights into common policy issues faced by selected ASEAN countries.

LMI country	UMI country	HI country
Cambodia Indonesia	China Thailand	Republic of Korea

Note: LMI denotes the lower-middle income and the low-income; UMI the upper-middle income; and HI the high-income.

For selected Asian countries, we present the results of exemplary diagnosis for all the indicators. In general, there are two types of presentation for indicators. When data is sufficiently available, four types of analysis are shown: a column chart showing each country's performance compared to average within its income group, a scatter chart with horizontal axis of growth (improvement rate between a certain period), then a transition path from LI, LMI, UMI, to HI based on average values of each income group, and the historical path of recently industrialized countries, that

Table 2: Data sources, country coverage and coverage time for all indicators

Indicator	Country Coverage	Coverage Time	Source	Data link & Alternative Source
Electricity generation installed capacity (kW) per 1 million people	195	1985-2021	Our World in Data	https://ourworldindata.org/grapher/per-capita-electricity-generation?tab=table
Fixed broadband subscriptions per 1000 people	130	2008-2019	ITU, World Telecommunication/ICT Indicators database via World Bank	https://data.worldbank.org/indicator/IT.NET.BBND.P2
Enrollment ratio in tertiary	118	2010-2020	UNESCO UIS database vis	https://data.worldbank.org/indicator/SE.TER.ENRR
Expenditure on R&D, % of GDP	48	1996-2021	UNESCO UIS database vis	https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS
Patents by foreigners per million	123	2004-2019	WIPO via World Bank	https://data.worldbank.org/indicator/IP.PAT.NRES
New business density per 1000	170	2006-2020	World Bank's Entrepreneurship I	https://data.worldbank.org/indicator/IC.BUS.NDNS.ZS
Market capitalization of listed domestic companies, % of GDP	102	1975-2020	World Federation of Exchanges via World Bank	https://tcdata360.worldbank.org/indicators/CM.MKT.LCAP.GD.ZS?country=BRA&indicator=1550&viz=line_chart&years=1975,2020
Share of firms exporting directly/indirectly (at least 10% of sales)	231	2008-2019	World Bank Enterprise Survey	https://www.enterprisesurveys.org/en/data/exploretopics/trade
Intellectual property payments per	196	1976-2020	International Monetary	Charges for the use of intellectual property, receipts (BoP,
International co-authored scientific	all	-2021	Scival, Scopus	https://www.scival.com/landing
Gross fixed capital formation as % of GDP	176	2006-2020	World Bank Enterprise Survey	https://data.worldbank.org/indicator/IC.BUS.NDNS.ZS
ISO 9001 certificates per 10 million people	116	2018-2019	ISO	https://www.iso.org/the-iso-survey.html
Scientific and technical articles per million people	133	2000-2018	National Science Foundation, Science and	https://data.worldbank.org/indicator/IP.JRN.ARTC.SC
Patents by resident per million	123	2004-2019	WIPO via World Bank	https://data.worldbank.org/indicator/IP.PAT.RESD
Public procurement, % of GDP	96	2007-2019	Global Public Procurement	https://www.globalpublicprocurementdata.org/gppd/
Share of ICT imports in total imports	162	2013-2020	UNIDO's Industrial Statistics Databases (INDSTAT)	
Share of medium/high-tech exports in total manufactured exports	151	1990-2019	UNCOMTRADE database via World Bank	https://data.worldbank.org/indicator/TX.MNF.TECH.ZS.UN

is Korea and China, validating the transition path drawn from the diagnosis. On the other hand, when data is not sufficient for the aforementioned analyses, two types of analysis are presented. The first type has two results of a column chart showing each country's performance compared to average within its income group and a scatter chart with horizontal axis of GDP per capita with an extrapolation equation. The second type has two results of a column chart showing each country's performance compared to average within its income group and a transition path of Korea and China.

Heatmap dashboard

Utilizing the comprehensive calculations of all indicators for each country examined in our analysis, we have devised a heatmap dashboard designed to facilitate comparative assessments of each country's overall performance against other exemplary nations or the averages within their income groups. This dashboard comprises three distinctive images/icons to depict a country's performance for a specific indicator: traffic lights (red, yellow, green), arrows indicating upward (↑) or downward (↓) trends, and alphabet grades (S, A, B, C, D), as follows:

Traffic light (comparative signal) for intra-income group competitiveness

The traffic light (comparative signal) enhances the visibility of intra-income group competitiveness. A red light denotes that a country's performance falls below 85% of the average value of its income group for a specific indicator; yellow indicates performance close to (85~115%) the income group average; and green signifies performance exceeding 115% of the income group average for a specific indicator.

Arrow signs for the rate (speed) of improvement (when applicable)

Plus (↑) and minus (↓) signs illustrate the rate (speed) of improvement over a recent period, where applicable. A minus (↓) sign indicates improvement below the income group average over a specified period for a specific indicator, while a plus (↑) sign

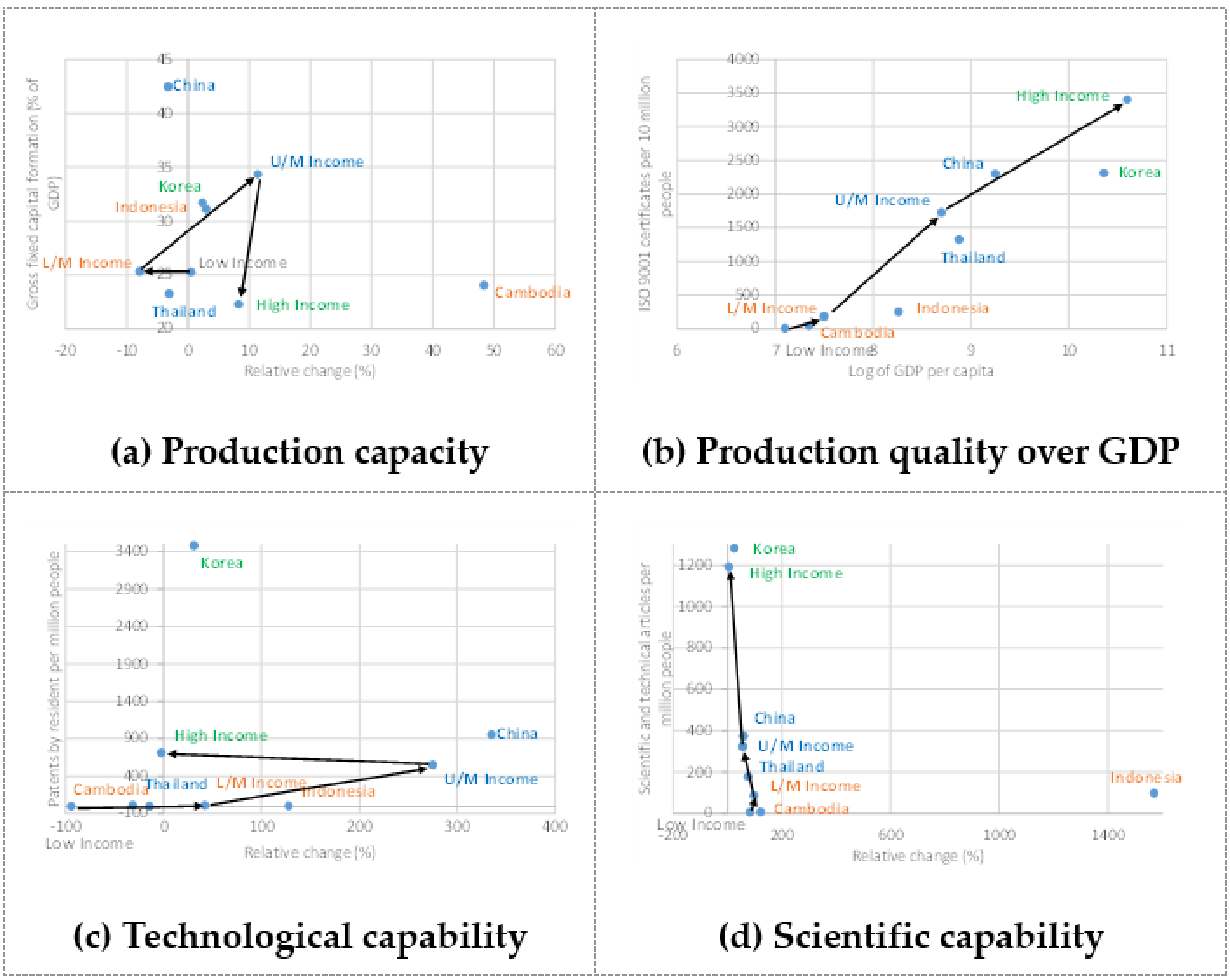


Figure 4: Pathway, changes and levels for actors and capabilities

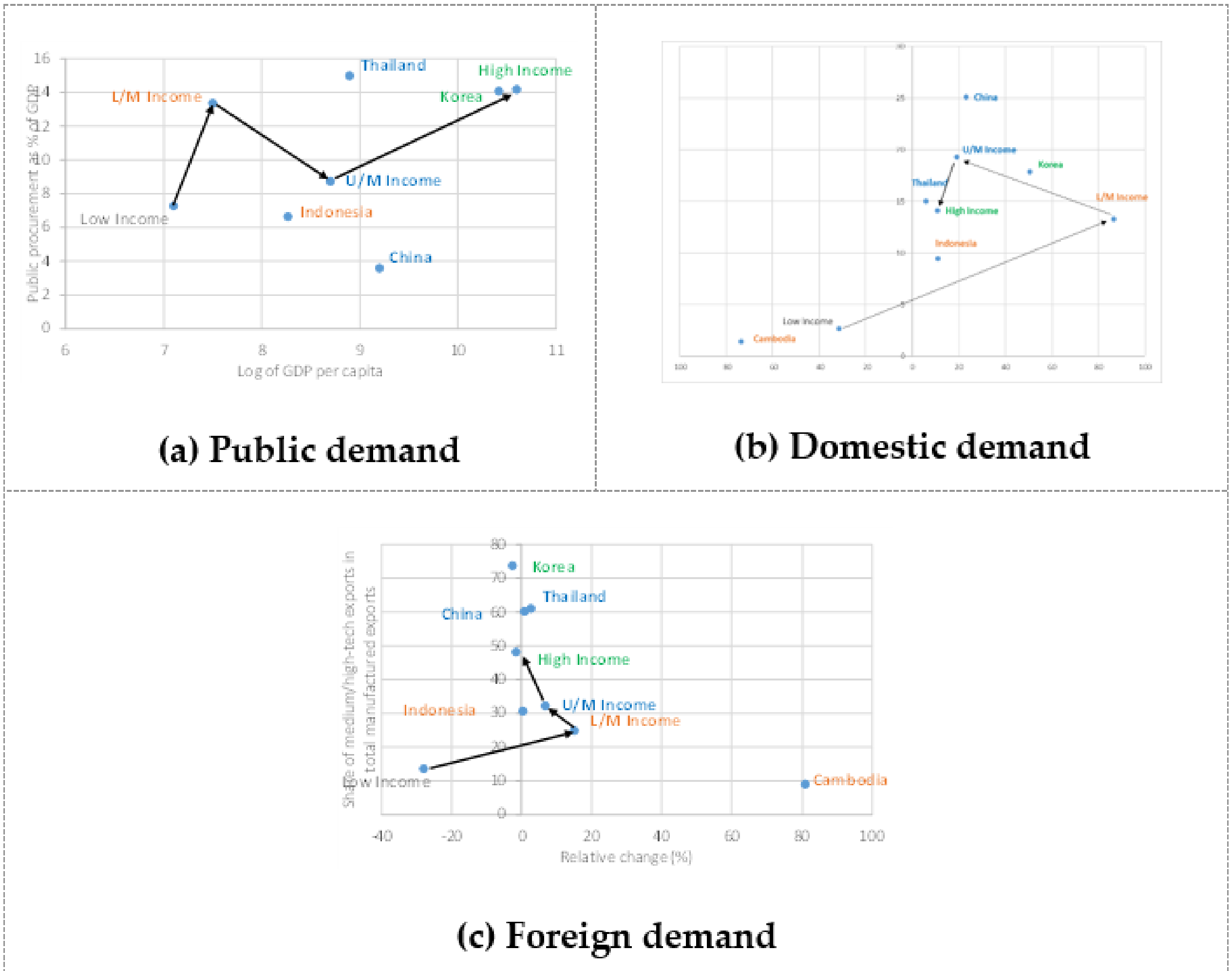


Figure 5: Pathway, changes and levels for demand articulation

signifies improvement above the income group average over the same period.

Alphabet grades for an absolute performance

Alphabet grades convey the absolute performance of each country relative to the average values of its income group. "D" denotes performance below the average of LI countries for a specific indicator; "C" indicates performance equal to or above the LI countries' average but below that of LMI countries; "B" signifies performance equal to or above the LMI countries' average but below that of UMI countries; and "A" indicates performance equal to or above the UMI countries' average but below that of HI countries. Finally, "S" denotes performance equal to or above the HI countries' average.

This integration of three images/icons within the heatmap dashboard enables readers to simultaneously visualize the following factors:

- The overall performance of a country across all analyzed indicators within the indicator system.
- The absolute performance of a country relative to the average values of all income groups in each indicator.
- The comparative performance of a country, indicating whether it is under- or over-performing and improving slower or faster against the average performance of its counterparts within the same income group (intra-income group comparison).

Concept of a radar chart

To provide readers with a comprehensive understanding of a country's overall performance concerning gaps, we developed country gap profiles featuring radar charts for Cambodia, Indonesia, Thailand, and China, as depicted in Appendix, respectively. In these radar charts, the average values for the LI, LMI, UMI, and HI groups for each indicator are standardized into quartiles: 25%, 50%, 75%, and 100%, respectively. Subsequently, the value of each indicator for a particular country is plotted accordingly, enabling readers to discern the country's relative position for each indicator and to interpret the gaps and challenges within the context of their respective countries.

Table 3: Values for all indicators

Component	Category	Sub-category	Indicator	HIC's average	UMIC's average	LMIC's average	LIC's average	Cambodia	Indonesia	Thailand	China
Reflexivity failure	Infrastructure	Physical	Electricity production capacity (kW) per capita	2479.8 (-7%)	1187.0 (37%)	248.1 (26%)	46.6 (-23%)	146.1 (477.5%)	1005 (34%)	2521 (16%)	5858 (72%)
		Digital	Fixed broadband subscriptions per 100 people	35.79 (37%)	26.13 (213%)	3.68 (273%)	0.47 (713%)	1.40 (461%)	4.29 (355%)	16.44 (240%)	33.60 (264%)
		Knowledge	Enrollment ratio in tertiary education	79 (9.9%)	58 (78.0%)	27 (45.0%)	9 (15.1%)	15 (28%)	36 (74%)	49 (9%)	58 (140%)
	Institution	R&D investment	Expenditure on R&D, % of GDP	2.37 (25%)	1.23 (62%)	0.52 (3%)	n/a	0.05 (137%)	0.08 (237%)	0.23 (387%)	1.71 (40%)
		IPR protection	Patents by foreigners per million people	560.88 (28%)	89.56 (29%)	18.77 (19%)	1.95 (30%)	14.83 (853%)	25.05 (34%)	95.44 (821%)	107.97 (55%)
		Business	New business registration per 1000 people (age 15-64)	4.60	6.30	0.44	n/a	0.54	n/a	1.29	8.58
		Finance	Market capitalization of listed domestic companies, % of GDP	1.34 (70%)	0.73 (80%)	0.69 (82%)	n/a	n/a	0.47 (38%)	1.08 (96%)	0.83 (203%)
	Interaction (or Network)	Production	Share of firms exporting directly/ indirectly (at least 10% of sales)	24	15	13	11	14	10	5	21
		Technology	Intellectual property payments per million GDP	7000 (38.4%)	2850 (29.6%)	1540 (30.2%)	83 (-57.9%)	808 (45%)	1445 (-32%)	9013 (-0.2%)	2578 (20%)
		Science	International co authored scientific articles per 100000 people	113.9 (21.2%)	15.6 (134.4%	5.8 (133.3%	2.1 (53.0%)	3 (152%)	3 (422%)	5 (-65%)	13 (211%)
	Capability	Production (capacity)	Gross fixed capital formation as % of GDP	22.29 (8.28%)	34.34 (11.4%)	25.31 (-7.9%)	25.27 (0.5%)	24.02 (48.4%)	31.72 (2.3%)	23.24 (-3.1%)	42.49 (-3.3%)
		Production (quality)	ISO 9001 certificates per 10 million people	3402	1727	183	10	47	251	1324	2301
		Technology	Patents by resident per million people	715.22 (1%)	551.53 (308%)	12.73 (65%)	0.90 (-93%)	0.06 (0%)	4.79 (157%)	12.36 (-29%)	953.14 (359%)
		Science	Scientific and technical articles per million people	1192.03 (8%)	323.43 (71%)	87.09 (129%)	8.16 (130%)	8.72 (160%)	98.52 (1788%)	179.28 (82%)	374.40 (69%)
Demand articulation failure	Domestic market	Public sector	Public procurement as % of GDP	14.2	8.7	13.4	7.3	n/a	7	15	4
		Private sector (domestic)	Share of ICT imports in total imports	14.1 (10.9%)	19.3 (19.0%)	13.3 (86.5%)	2.7 (-31.6%)	1 (-74%)	9 (11%)	15 (6%)	25 (23%)
	Int'l market	Private sector (foreign)	Share of medium/high-tech exports in total manufactured exports	48 (-1.6%)	32 (6.8%)	25 (15.0%)	14 (-28.0%)	9 (81%)	30 (0.4%)	61 (3%)	60 (0.8%)

Table 4: Summary of heatmap dashboard

Tool title	Component	Category	Sub-category	Indicator	Cambodia	Indonesia	Thailand	China
System failure framework	Reflexivity	Infrastructure	Physical	Electricity production capacity (kW) per 100,000 people	C↑	C↑	B-	A↑
			Digital	Fixed broadband subscriptions per 100 people	C↑	B↑	B↑	A↑
			Knowledge	Enrollment ratio in tertiary education	C↓	B↑	B↓	A↑
		Institution	R&D investment	Expenditure on R&D, % of GDP	C↑	C↑	C↑	A↓
			IPR protection	Patents by foreigners per million people	C↑	B↑	A↑	A↑
			Business	New business registration per 1000 people (age 15-64)		n/a		
			Finance	Market capitalization of listed domestic companies, % of GDP	n/a	C↓	A↑	A↑
		Interaction (or Network)	Production	Share of firms exporting directly/ indirectly (at least 10% of sales)	B	D	D	A
			Technology	Intellectual property payments per million GDP	C↑	C↑	S↓	B↓
			Science	International co-authored scientific articles per 100000 people	C↑	C↑	C↓	B↑
		Capability	Production (capacity)	Gross fixed capital formation as % of GDP	C	B	C	A
			Production (quality)	ISO 9001 certificates per 10 million people	C	B	B	A
			Technology	Patents by resident per million people	D↓	C↑	C↓	S↑
			Science	Scientific and technical articles per million people	C↑	B↑	B↑	A↓
	Demand articulation	Domestic market	Public sector	Public procurement as % of GDP	n/a			
			Private sector (domestic)	Share of ICT imports in total imports	D↓	C↓	B↓	S↑
		Int'l market	Private sector (foreign)	Share of medium/high-tech exports in total manufactured exports	D↑	B↓	S↓	S↓

ANALYSIS AND RESULTS

A Brief Overview of Innovation and Industry Policies of the Studied Countries

Cambodia

In recent years, Cambodia's innovation policy has seen notable development. Recognizing the importance of fostering Science, Technology, and Innovation (STI) as catalysts for economic progress, the Cambodian government began adopting STI policies under its economic development plan, namely the Rectangular Strategy. Since then, the government has implemented various policies and initiatives aimed at promoting entrepreneurship, such as the STI Master Plan 2030, the establishment of the Ministry of Industry, Science, Technology, and Innovation in 2020, and the National Strategic Technology Roadmaps in 2023. These efforts enhance access to education and technology and foster collaboration between the public and private sectors. Despite its commitment to harnessing innovation as a driver of sustainable development and economic prosperity, Cambodia still faces limited access to technical expertise, R&D funding, and knowledge transfer opportunities.

Indonesia

Indonesia's innovation policy has undergone significant evolution, reflecting the country's commitment to fostering economic development through STI. Initially, innovation efforts were relatively nascent, with limited emphasis on Research and Development (R&D) and technological advancement. However, recognizing the pivotal role of STI in driving sustainable growth, the Indonesian government initiated a strategic shift towards prioritizing the development of its innovation ecosystem. This transformation involved forging strategic partnerships with international organizations and foreign governments to access technical expertise, funding, and knowledge transfer opportunities, thus laying the groundwork for accelerated innovation and economic progress.

Thailand

As an upper-middle-income country, Thailand's innovation policy has evolved significantly. The country aspires to transition towards a knowledge-based economy and enhance its global competitiveness. Initially, Thailand focused its innovation efforts predominantly on import substitution industrialization, aiming to reduce reliance on foreign imports through the promotion of domestic goods production. However, this approach had limited success, prompting a shift towards an export-oriented strategy centered on attracting foreign direct investments. This shift facilitated robust economic growth until the late 1990s. Nevertheless, the emphasis on this strategy led to a relative neglect of cultivating indigenous R&D capabilities, constraining Thailand's capacity to stimulate innovation-led economic expansion. Consequently, Thailand appears to have encountered challenges commonly associated with the "middle-income trap," with its current per capita GDP persisting at an upper-middle-income level.[32] Challenges such as limited R&D funding, inadequate intellectual property protection, and a lack of coordination between stakeholders have persisted, highlighting the need for continued reform and investment in Thailand's innovation ecosystem.

China

As an upper-middle-income country, China has demonstrated remarkable progress in the fields of science, technology, and innovation, transitioning from being the world's factory to a global industrial powerhouse and now a global leader in various technological domains. Over the past few decades, China's innovation policy has undergone substantial evolution. Initially, from the late 1970s to the early 1990s, the focus was on importing foreign technologies through joint ventures and technology transfers. However, this strategy heavily relied on foreign expertise and failed to cultivate indigenous innovation capabilities within the country. Since the early 2000s, there has been a notable shift towards fostering domestic innovation capabilities through increased investment in R&D. This shift was underscored by policies such as the "National Innovation-Driven Development Strategy" and the "Made in China 2025" initiative, which emphasized the pivotal role of innovation in propelling economic growth and bolstering China's global competitiveness.[5]

Infrastructure

In the context of infrastructure, we identify three distinct indicators, each representing the physical, ICT (Information and Communication Technology), and knowledge dimensions, respectively (Figure 1). For Low and Middle-Income (LMI) countries to reach the infrastructure levels observed in Upper Middle-Income (UMI) countries, significant increases are required across these dimensions. Specifically, physical infrastructure, exemplified by electricity generating capacity, must increase nearly fivefold (from 248.1 kW per 1 million people to 1,187.0 kW). ICT infrastructure, as indicated by the number of fixed broadband subscriptions per 100 people, requires a sevenfold increase (from 3.7 to 26.1 per 100 people). Lastly, knowledge infrastructure, measured by tertiary education enrollment rates, needs to double (from 27% to 58%).

Next, we examine our focal countries. Overall, Korea surpasses its income group (i.e., high-income group) across all three infrastructure dimensions, demonstrating exceptional performance. China also exceeds expectations in the physical and ICT dimensions, while it performs on par in the knowledge dimension. Considering its growth rate between 2010 and 2020, as indicated by the horizontal axis of each graph, China is expected to reach the high-income group level very soon in all three dimensions.

Table 5: Cambodia country profile

Tool title	Component	Category	Sub-category	Indicator	HIC's average	UMIC's average	LMIC's average	LIC's average	Indonesia
System failure framework	Reflexivity failure	Infrastructure	Physical	Electricity production capacity (kW) per capita	2479.0 (-7%)	1107.0 (37%)	260.1 (26%)	46.6 (-23%)	248.4 (53.5%)
			Digital	Fixed broadband subscriptions per 100 people	35.79 (37%)	26.13 (213%)	3.60 (273%)	0.47 (713%)	4.29 (305%)
			Knowledge	Enrollment ratio in tertiary education	79 (9.9%)	58 (78.0%)	27 (45.0%)	9 (15.1%)	16 (74%)
		Institution	R&D investment	Expenditure on R&D, % of GDP	2.37 (25%)	1.23 (62%)	0.52 (0%)	n/a	0.08 (287%)
			IPR protection	Patents by foreigners per million people	560.88 (28%)	89.56 (29%)	18.77 (19%)	1.95 (30%)	25.05 (64%)
			Business	New business registration per 1000 people (age 15-64)	4.60	6.30	0.48	n/a	n/a
			Finance	Market capitalization of listed domestic companies, % of GDP	1.34 (70%)	0.73 (80%)	0.69 (82%)	n/a	0.47 (98%)
		Interaction (or Network)	Production	Share of firms exporting directly/ indirectly (at least 10% of sales)	24	15	13	11	10
			Technology	Intellectual property payments per million GDP	7000 (38.4%)	2850 (29.6%)	1540 (30.2%)	83 (-57.9%)	1845 (-3.2%)
			Science	International co-authored scientific articles per 100000 people	113.9 (21.2%)	15.6 (134.4%)	5.8 (133.3%)	2.1 (53.0%)	3 (42%)
		Capability	Production (capacity)	Gross fixed capital formation as % of GDP	22.29 (0.20%)	34.34 (11.4%)	25.31 (-7.9%)	25.27 (0.5%)	31.72 (2.3%)
			Production (quality)	ISO 9001 certificates per 10 million people	3402	1727	183	10	251
			Technology	Patents by resident per million people	715.22 (1%)	551.53 (308%)	12.73 (63%)	0.90 (-93%)	4.79 (157%)
			Science	Scientific and technical articles per million people	1192.03 (0%)	323.43 (71%)	87.09 (129%)	0.16 (130%)	98.52 (1780%)
	Demand articulation failure	Domestic market	Public sector	Public procurement as % of GDP	14.2	8.7	13.4	7.3	7
			Private sector (domestic)	Share of ICT imports in total imports	14.1 (10.9%)	19.3 (19.0%)	13.3 (86.5%)	2.7 (-31.6%)	9 (11%)
		Int'l market	Private sector (foreign)	Share of medium/high-tech exports in total manufactured exports	48 (-1.6%)	32 (6.8%)	25 (15.0%)	14 (-20.0%)	30 (0.4%)

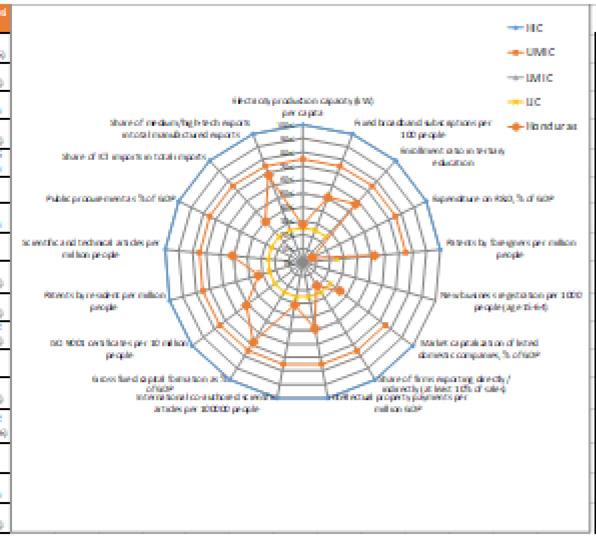
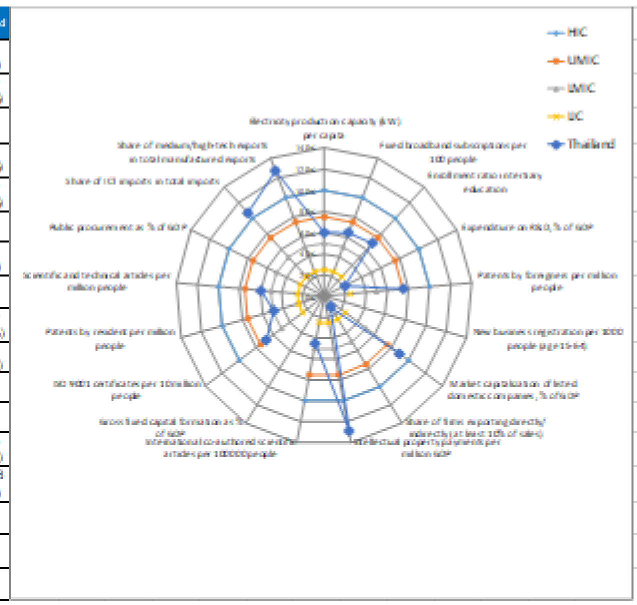


Table 6: Indonesia country profile

Component	Category	Sub-category	Indicator	HIC's average	UMIC's average	LMIC's average	LIC's average	Thailand
Reflexivity failure	Infrastructure	Physical	Electricity production capacity (kW) per capita	2479.0 (-7%)	1107.0 (37%)	260.1 (26%)	46.6 (-23%)	2521 (16%)
		Digital	Fixed broadband subscriptions per 100 people	35.79 (37%)	26.13 (213%)	3.60 (273%)	0.47 (713%)	16.44 (240%)
		Knowledge	Enrollment ratio in tertiary education	79 (9.9%)	58 (78.0%)	27 (45.0%)	9 (15.1%)	49 (9%)
	Institution	R&D investment	Expenditure on R&D, % of GDP	2.37 (25%)	1.23 (62%)	0.52 (0%)	n/a	0.23 (387%)
		IPR protection	Patents by foreigners per million people	560.88 (28%)	89.56 (29%)	18.77 (19%)	1.95 (30%)	95.44 (821%)
		Business	New business registration per 1000 people (age 15-64)	4.60	6.30	0.44	n/a	
		Finance	Market capitalization of listed domestic companies, % of GDP	1.34 (70%)	0.73 (80%)	0.69 (82%)	n/a	1.08 (86%)
	Interaction (or Network)	Production	Share of firms exporting directly/ indirectly (at least 10% of sales)	24	15	13	11	5
		Technology	Intellectual property payments per million GDP	7000 (38.4%)	2850 (29.6%)	1540 (30.2%)	83 (-57.9%)	9013 (-0.2%)
		Science	International co-authored scientific articles per 100000 people	113.9 (21.2%)	15.6 (134.4%)	5.8 (133.3%)	2.1 (53.0%)	5 (-65%)
	Capability	Production (capacity)	Gross fixed capital formation as % of GDP					
		Production (quality)	ISO 9001 certificates per 10 million people	3402	1727	183	10	1824
		Technology	Patents by resident per million people	715.22 (1%)	551.53 (308%)	12.73 (65%)	0.90 (-93%)	12.36 (-29%)
		Science	Scientific and technical articles per million people	1192.03 (0%)	323.43 (71%)	87.09 (129%)	0.16 (130%)	170.28 (82%)
Demand articulation failure	Domestic market	Public sector	Public procurement as % of GDP	14.2	8.7	13.4	7.3	15
		Private sector (domestic)	Share of ICT imports in total imports	14.1 (10.9%)	19.3 (19.0%)	13.3 (86.5%)	2.7 (-31.6%)	15 (6%)
	Int'l market	Private sector (foreign)	Share of medium/high-tech exports in total manufactured exports	48 (-1.6%)	32 (6.8%)	25 (15.0%)	14 (-20.0%)	61 (3%)



Thailand and Cambodia lag behind their respective income groups. However, their future growth potential diverges. While Cambodia is expected to rapidly reach the level of the next income group (i.e., Upper Middle-Income) in physical and ICT infrastructure, Thailand shows sluggish progress in all three dimensions. Cambodia, however, still needs to invest more in knowledge infrastructure or find ways to expand its tertiary education enrollment. Indonesia largely aligns with the performance of its income group. In terms of growth rate, Indonesia is slightly ahead of its income group (LMI) in ICT and knowledge infrastructure.

Expanding infrastructure generally requires significant investment and time. Also, as illustrated by the substantial gaps between LMI and UMI, and between UMI and HI in all three infrastructure dimensions, three ASEAN countries need a strategic approach to their development. In particular, Cambodia needs to focus on enhancing its tertiary education foundation. Thailand and Indonesia need to concentrate more on improving their electricity generating facilities.

Institution

In the context of institutions, we identify four distinct indicators, each measuring R&D investment, innovation attractiveness (as indicated by non-resident patents), new business creation, and market financing, respectively (Figure 2). For LMI countries to reach the institutional levels observed in UMI countries, they need to overcome significant gaps in both R&D investment (a 277% increase) and new business creation (a 1435% increase!). Significant gaps also exist for UMI countries to enter the High-Income (HI) group, requiring increases in R&D investment (48%), Innovation attractiveness (626%), and market financing of firms (215%).

Korea demonstrates above-average performance in both R&D investment and Innovation attractiveness but underperforms in new business creation and market financing. China stands out in new business creation and exhibits strong performance in the other three institutional aspects within its income group (i.e., UMI).

Thailand and Cambodia demonstrate impressive dynamism in enhancing all aspects of institutional development, as indicated by above-average growth rates for all four indicators—with the exception of market capitalization for Cambodia, for which data is not available, and underperforming new business creation in Thailand. Indonesia has significantly increased its R&D investment recently and shows slightly better performance in innovation attractiveness, yet it lags behind in both new business creation and market financing.

In terms of the institutional aspects of national innovation systems, China is clearly an aggressive contender for the High-Income club. Korea excels in Science, Technology, and Innovation (STI) institutions but faces challenges in business institutions. Indonesia also needs to enhance its new business creation and stock market development. Thailand and Cambodia are on the right track in their institutional development.

Interaction and network

In the context of interactions, we identify three distinct indicators: the share of exporting firms, which measures international interactions in production; intellectual property payments, indicating technology payments; and the presence of internationally co-authored scientific papers, reflecting science internationalization (Figure 3). For all three indicators, the gap between LMI and UMI countries is significantly closer than the gap between UMI and HI countries. This suggests that stronger international engagement is a critical step for UMI countries to overcome the middle-income trap.

Korea and China underperform in both technology and science interactions, although China excels among its income peers in the share of exporting firms (data for exporting firms for Korea are not available).

Thailand and Indonesia lag behind in export and science interactions. Thailand exhibits an exceptionally high level of technology payments, while Indonesia and Cambodia trail behind their peers in the LMI group.

In terms of the interaction aspects of national innovation systems, all five countries tend to underperform, except Cambodia and China in the share of exporting firms and Thailand in technology payments. Nevertheless, internationalizing their innovation systems may not be as critical when a country moves from LMI to UMI as it is when a country leaps from UMI to HI groups. Therefore, it is imperative for Thailand to implement effective policies to expand its base of exporting firms and enhance international collaboration in science. Concurrently, China may need to revisit its technology licensing policies to facilitate the influx of foreign technology.

Table 7: Thailand country profile

Component	Category	Sub-category	Indicator	HIC's average	UMIC's average	LMIC's average	LIC's average	PRC
Reflexivity	Infrastructure	Physical	Electricity production capacity (kW) per capita	2479.0 (-7%)	1107.0 (37%)	240.1 (26%)	46.6 (-23%)	5858 (72%)
		Digital	Fixed broadband subscriptions per 100 people	35.79 (87%)	26.13 (213%)	3.68 (273%)	0.47 (713%)	33.60 (264%)
		Knowledge	Enrollment ratio in tertiary education	79 (9.9%)	58 (78.0%)	27 (85.0%)	9 (15.1%)	58 (140%)
	Institution	R&D investment	Expenditure on R&D, % of GDP	2.37 (25%)	1.23 (62%)	0.52 (3%)	n/a	1.71 (40%)
		IPR protection	Patents by foreigners per million people	560.88 (28%)	89.56 (29%)	18.77 (19%)	1.95 (30%)	107.97 (55%)
		Business	New business registration per 1000 people (age 15-64)	4.60	6.30	0.44	n/a	
		Finance	Market capitalization of listed domestic companies, % of GDP	1.34 (70%)	0.73 (80%)	0.69 (82%)	n/a	0.83 (203%)
	Interaction (or Network)	Production	Share of firms exporting directly/ indirectly (at least 10% of sales)	24	15	13	11	21
		Technology	Intellectual property payments per million GDP	7000 (38.4%)	2050 (29.6%)	1540 (80.2%)	83 (-57.9%)	2578 (20%)
		Science	International co-authored scientific articles per 100000 people	113.9 (21.2%)	15.6 (134.4%)	5.8 (103.3%)	2.1 (53.0%)	13 (211%)
	Capability	Production (capacity)	Gross fixed capital formation as % of GDP					
		Production (quality)	ISO 9001 certificates per 10 million people	3802	1727	183	10	2301
		Technology	Patents by resident per million people	715.22 (1%)	551.53 (308%)	12.73 (65%)	0.90 (-93%)	953.14 (359%)
		Science	Scientific and technical articles per million people	1192.03 (0%)	323.43 (71%)	87.09 (129%)	8.16 (130%)	374.40 (69%)
Demand articulation	Domestic market	Public sector	Public procurement as % of GDP	14.2	8.7	13.4	7.3	4
		Private sector (domestic)	Share of ICT imports in total imports	14.1 (10.9%)	19.3 (19.0%)	13.3 (86.5%)	2.7 (-31.6%)	25 (23%)
	Int'l market	Private sector (foreign)	Share of medium/high-tech exports in total manufactured exports	48 (-1.6%)	32 (6.0%)	25 (15.0%)	14 (-20.0%)	60 (0.8%)

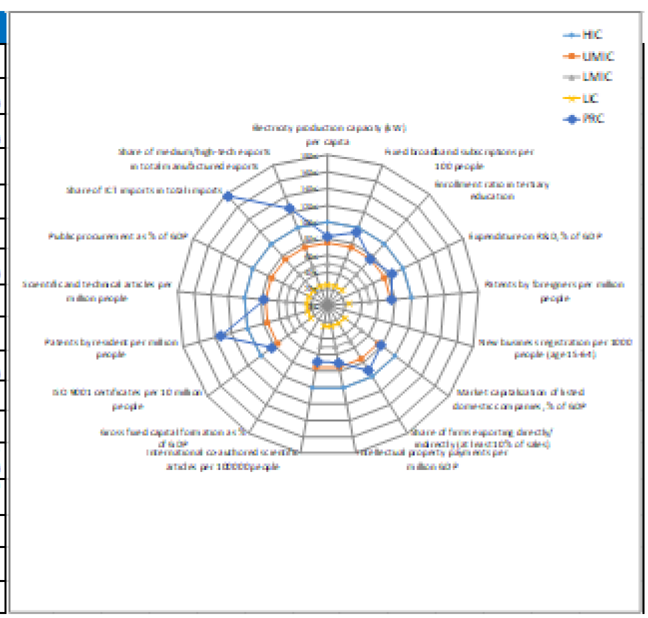
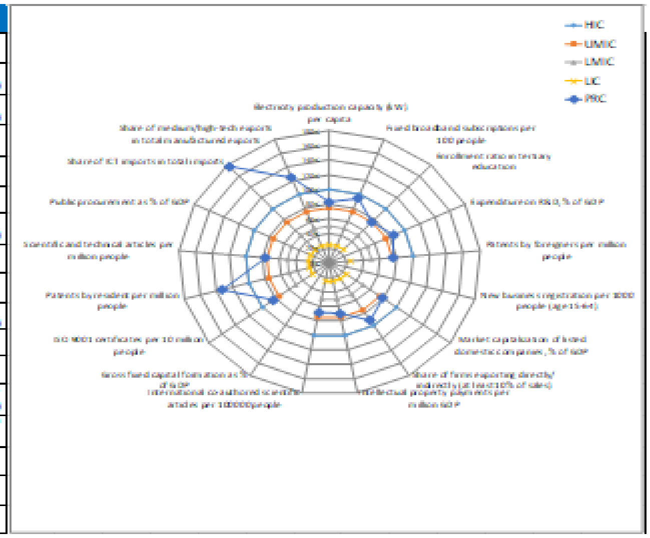


Table 8: China country profile

Component	Category	Sub-category	Indicator	HIC's average	UMIC's average	LMIC's average	LIC's average	PRC
Reflexivity	Infrastructure	Physical	Electricity production capacity (kW) per capita	2479.0 (-7%)	1107.0 (37%)	240.1 (26%)	46.6 (-23%)	5858 (72%)
		Digital	Fixed broadband subscriptions per 100 people	35.79 (37%)	26.13 (213%)	3.68 (273%)	0.47 (713%)	33.60 (264%)
		Knowledge	Enrollment ratio in tertiary education	79 (9.9%)	58 (78.0%)	27 (85.0%)	9 (15.1%)	58 (140%)
	Institution	R&D investment	Expenditure on R&D, % of GDP	2.37 (25%)	1.23 (62%)	0.52 (3%)	n/a	1.71 (40%)
		IPR protection	Patents by foreigners per million people	560.88 (28%)	89.56 (29%)	18.77 (19%)	1.95 (30%)	107.97 (55%)
		Business	New business registration per 1000 people (age 15-64)	4.60	6.10	0.44	n/a	
		Finance	Market capitalization of listed domestic companies, % of GDP	1.34 (70%)	0.73 (80%)	0.69 (62%)	n/a	0.83 (203%)
	Interaction (or Network)	Production	Share of firms exporting directly/ indirectly (at least 10% of sales)	24	15	13	11	21
		Technology	Intellectual property payments per million GDP	7000 (38.4%)	2850 (29.6%)	1540 (80.2%)	83 (-57.9%)	2578 (20%)
		Science	International co-authored scientific articles per 100000 people	113.9 (21.2%)	15.6 (134.4%)	5.8 (183.3%)	2.1 (53.0%)	13 (211%)
	Capability	Production (capacity)	Gross fixed capital formation as % of GDP					
		Production (quality)	ISO 9001 certificates per 10 million people	3402	1727	183	10	2301
		Technology	Patents by resident per million people	715.22 (1%)	551.53 (308%)	12.73 (65%)	0.90 (-93%)	953.14 (359%)
		Science	Scientific and technical articles per million people	1192.03 (8%)	323.43 (71%)	87.09 (129%)	8.16 (130%)	374.40 (69%)
Demand articulation	Domestic market	Public sector	Public procurement as % of GDP	14.2	8.7	13.4	7.3	4
		Private sector (domestic)	Share of ICT imports in total imports	14.1 (10.9%)	19.3 (19.0%)	13.3 (86.5%)	2.7 (-31.6%)	25 (23%)
	Int'l market	Private sector (foreign)	Share of medium/high tech exports in total manufactured exports	48 (-1.6%)	32 (6.0%)	25 (15.0%)	14 (-20.0%)	60 (0.8%)



Actors and capabilities

For actors and capabilities, we identify four distinct indicators: production capacity, measured by gross fixed capital formation; production quality, as indicated by the number of ISO 9001 certificates; technology capability, measured by domestic patents; and scientific capability, reflected in academic articles in science and technology fields (Figure 4). Regarding the latter three indicators, the performance levels between LMI and UMI, and between UMI and HI countries, are increasing. Enhancing production capacity through reinvestment in fixed assets is crucial for a country aiming to leap from LMI to UMI, likely due to the necessity of bolstering the manufacturing sector through capital accumulation. However, its importance diminishes when a country aims for the HI group. This shift suggests that stronger service sectors and intangible assets play pivotal roles in transitioning economies from UMI to HI standards. Given the structural shift implied by the production capacity indicator, we do not compare the level of each country along the pathway for this indicator.

Korea excels in both technological and scientific capabilities but lags behind in production quality. China, again, excels in all three indicators compared to peers in UMI group.

Thailand, Indonesia, and Cambodia lag behind in the aforementioned three indicators. However, Indonesia is rapidly developing its scientific capabilities and production quality compared to its peers in the Low- and Middle-Income (LMI) group. Thailand needs to strengthen its domestic patent capability to align with the Upper Middle-Income (UMI) average.

Regarding production capacity, the rapid increase in Cambodia's reinvestment and potential for capital accumulation is noteworthy. Unlike other countries, the level and change in Thailand's capital reinvestment are significantly low.

Demand articulation

For demand articulation, we identify three distinct indicators: public sector demand, measured by the share of public procurement in GDP; domestic demand for ICT goods, as measured by the share of ICT imports in total imports; and foreign demands, as measured by the share of medium and high-tech exports in all manufactured exports (Figure 5). While the foreign demand indicator shows a monotonous increase along with income level, the other two indicators exhibit fluctuations across income levels. For public procurement, both HI and LMI groups are higher than UMI and LI groups. Domestic demand (or ICT imports share) decreases in HI countries. This pattern may be partly explained by the internalization of supply chains and the globalization of production and business networks in advanced economies.

Regarding public procurement, Korea and Thailand exhibit high levels (>15% of GDP), while China and Indonesia show low levels (<7% of GDP).

Consistent with the well-known fact, Korea and China have a clear industrial pathway toward the ICT industry, which is reflected in their above-average levels in our domestic demand indicator. The remaining three ASEAN countries all exhibit below-average levels.

Lastly, concerning foreign demand, all countries under study, except for Cambodia, demonstrate superior performance levels. Interestingly, the growth rate over the last ten years shows an exactly opposite pattern against the current levels, meaning only Cambodia exceeded the growth of its peer group.

Heatmap Dashboard

An analysis derived from the heatmap dashboard (Table 4) indicates that Cambodia generally lags behind its comparator countries within the LMI group. The dashboard reveals numerous red lights across most indicators, with only two instances of yellow lights observed within the country's portfolio. Despite these challenges, there are signs of progress, with eight upward arrows noted in the heatmap dashboard, signaling improvement efforts across various indicators. Notably, Cambodia outperforms its LMI comparators in terms of the number of new business registrations, indicating some positive strides in fostering entrepreneurial activity. However, significant enhancements are necessary across multiple indicator areas to further bolster Cambodia's innovation capacity. Nevertheless, the country's recent endeavors demonstrate a visible commitment to addressing these challenges and advancing its innovation agenda. A country profile of Cambodia for all indicators is presented in Table 5.

The analysis derived from the heatmap dashboard presents a nuanced picture of Indonesia's innovation performance, characterized by a balance of positive and negative aspects. The country demonstrates commendable performance in certain areas, as indicated by seven green lights, while also encountering challenges highlighted by six red lights. Notably, negative aspects manifest in indicators such as the number of new business registrations, the share of firms exporting more than 10% of sales, the number of international co-authored scientific articles, and the number of patent applications by residents. Of particular concern is Indonesia's lag behind its LMI comparator countries, especially in the share of firms exporting more than 10% of sales, where it even falls behind LI group. This underscores the imperative for Indonesia to prioritize its innovation policies, directing focused efforts towards improving these negatively marked indicators, while leveraging its strengths to enhance its overall innovation portfolio. A country profile of Indonesia for all indicators is presented in Table 6.

The analysis derived from the heatmap dashboard reveals a mixed performance for Thailand. The country exhibits both positive and negative aspects across various indicators. Notably, there are instances of positive performance, denoted by four green lights, particularly in areas such as market capitalization of listed domestic companies, intellectual property payments, public procurement, and the share of medium/high-tech exports. However, Thailand lags behind its UMI comparator countries in several areas, particularly in the share of firms exporting more than 10% of sales, where it falls even behind LI group. This disparity underscores the need for concerted efforts by the Thai government to enhance its innovation system across multiple indicators. Addressing these areas of weakness is imperative for Thailand to strengthen its innovation ecosystem and bolster its competitiveness. A country profile of Thailand for all indicators is presented in Table 7.

In line with the recent development of China, the heatmap dashboard analysis shows an overall strong performance in most categories in its portfolio, with eleven green lights, four yellow lights, and only one red light in the indicator of public procurement as a percentage of GDP. The only area where the country needs to improve is international interaction (network) in science and technology, which is also observed in other East Asian countries such as Japan and Korea. China may compensate for this gap with domestic technological capabilities. According to NISTEP (2022), China has already surpassed the United States in terms of both the quantity and quality of scientific publications. Therefore, this should be interpreted in a more in-depth way within its national policy contexts. China also shows a strong performance in absolute terms with three Ss and ten As, demonstrating the strength of its innovation system comparable to high-income countries in diverse areas. A country profile of China for all indicators is presented in Table 8. In conclusion, China needs to monitor its performance compared to higher standards, the average performance of the high-income group, to enhance its innovation capacity.

DISCUSSION AND CONCLUSION

In the examination of institutional and interaction frameworks, countries demonstrate varied performance across R&D investment, innovation attractiveness, new business creation, market financing, international production interactions, technology payments, and science internationalization. LMI countries face substantial challenges in bridging the gap to UMI and HI standards, with significant increases needed in R&D investment and new business creation to progress. Korea shows strength in R&D investment and innovation attractiveness but falls short in new business creation and market financing. In contrast, China excels in new business creation and maintains strong performance across other institutional indicators, positioning itself as a formidable contender for HI status. Thailand and Cambodia exhibit dynamic institutional development, with Thailand needing to enhance its domestic patent capabilities and Cambodia showing rapid capital accumulation. On the interaction front, the gap between LMI and UMI countries is narrower than that between UMI and HI countries, suggesting that greater international engagement could be key for UMI countries to escape the middle-income trap. Despite this, countries like Korea and China underperform in technology and science interactions, with Thailand and Indonesia lagging in export and science interactions.

This analysis underscores the complexity of national innovation systems and the multifaceted approach required for development. While countries like China and Korea present robust frameworks in certain aspects, there is a clear need for strategic policy interventions to address shortcomings in new business creation, market financing, and international collaborations. For LMI countries aiming to transition to higher income brackets, prioritizing R&D investment, fostering an environment conducive to new business creation, and enhancing international engagement emerge as critical steps. Moreover, as countries progress, the focus shifts towards strengthening service sectors and intangible assets, indicating a transition in developmental priorities. This intricate dance of progress and policy underscores the need for a tailored approach, recognizing the unique challenges and strengths of each country's innovation ecosystem.

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