Journal of Open Innovation: Technology, Market, and Complexity

MDPI

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Can Developing Countries 'Catch Up' with Weak S&T Eco-Systems: Some Insights from Dynamic Asian Economies

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Abstract: The post-war era, particularly from the mid-1980s, can be seen as a turning point for various Asian countries. Japanese success in industrialisation based on technology transfer from the industrialised West and evolution of unique endogenous scientific and technological capacities led scholars to conceptualise 'late industrialisation' and 'catching up' strategies. In a large measure, the 'East Asian Miracle' led to some erroneous misconceptions on science, technology, and innovation (STI) policies. Various writings and commentators from Africa, Asia and Latin America advocated to follow the path of East Asian Dragons. These writings begun to assume that countries can build innovation systems or dynamic technological sectors of economy within their respective countries, without paying much attention to building and strengthening science and technology (S&T) eco-systems. There are now clear STI policy signals which point to the significance of building science and technology systems before fully embarking on innovation policies. Drawing on some exemplary cases, this essay will explore the importance of S&T systems in the context of developing countries.

Keywords: catch up; S&T eco-system; Asian Dragons; developing countries

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Citation: Krishna, V.V. Can Developing Countries 'Catch Up' with Weak S&T Eco-Systems: Some Insights from Dynamic Asian Economies. *J. Open Innov. Technol. Mark. Complex.* **2022**, *8*, 175. https://doi.org/10.3390/joitmc8040175

Received: 27 August 2022
Accepted: 19 September 2022
Published: 27 September 2022

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1. Introduction

The role of science and technology (S&T) in the process of economic growth and development has been a recurrent theme in S&T policy agendas of developing countries over the last four decades. In the 1980s there was indeed a clear distinction between industrially advanced or developed countries and underdeveloped or developing countries. As early as 1966, Indian nuclear physicist, Homi Bhabha, remarked that, 'what the developed countries have and the underdeveloped lack is modern science and an economy based on modern technology. The problem of developing the underdeveloped countries is therefore the problem of establishing modern science in them and transforming their economy'. Two decades later, Abdus Salam, N.L and founding President of The Third World Academy of Sciences, Trieste, Italy, again reminded the world about the gap between rich and poor countries in 1988:

> *This globe of ours is inhabited by two distinct types of humans. According to the UNDP count of 1983, one-quarter of mankind—some 1.1 billion people—are developed. They inhabit two-fifths of the land area of the Earth and control 80% of the world's natural resources, while 3.6 billion developing humans—'les misa bles', the 'mustazeffin'—live on the remaining three-fifths of the globe. What distinguishes one type of human from the other is the ambition, the power, the elan which basically stems from their differing mastery and utilization of present-day science and technology. It is a political decision on the part of those (principally from the South) who decide on the destiny of developing humanity if they will take steps to let the less miserable create, master and utilize modern science and technology for their betterment.* [1]

The decades of the 1980s and 1990s witnessed a plethora of policy discourses coming from science policy experts as well as international agencies, advising decision makers of developing countries to promote S&T institutions and infrastructure. In Africa, Lagos

Plan of Action of 1980 called for governments to mobilize 1% of GDP towards building S&T capabilities. UNESCO recurrently advised and pleaded with the developing country governments to invest so as to match the 'magic figure' of 1% of GDP for research and development (R&D) since the 1990s [2–4]. Africa's Science and Technology Consolidated Action Plan of African Union in 2005 reiterated this demand for the continent as a whole [5]. Most recently, the two UNESCO Science Reports in 2015 and 2021 revealed that only dozen developing countries, such as China, India, Singapore, Malaysia, Brazil, and South Africa, crossed this magic figure or reached close to it during the last decade [6,7]. By all indicators, the bulk of developing countries in Africa, Asia and Latin America are still underdeveloped in so far as their S&T and R&D endowments are concerned [6,8]. The impact of globalization and liberal economic policies further accentuated the gulf between industrially advanced and developing countries. In a large measure, the phase of globalization led to some 'winners' and many 'losers'. After more than four decades, Homi Bhabha and Abdus Salam's prophetic observations still holds good and relevant in the context of developing world. The rise of Asia, particularly the remarkable economic progress of East Asian Dragons, created ripples in the developing world.

The post-war era, particularly from the mid-1980s, can be seen as a turning point. Japanese success in industrialization based on technology transfer from the industrialized West and evolution of unique endogenous scientific and technological capacities led scholars to conceptualize 'late industrialization' and 'catching up' strategies. Alice Amsden's book on *Asia's Next Giant: South Korea and Late Industrialization* is probably the single most highly cited work on East Asian development [9]. What has come to be known as '*Imitation to Innovation*' was the main title of Linsu Kim's *The Dynamics of Korea's Technological Learning* [10]. The technological dynamics in the region soon came be characterized as *East Asian Miracle* by the World Bank in the 1990s. In a large measure, this, led to some erroneous misconceptions on science, technology, and innovation (STI) policies. Various writings, science and technology policy documents, and commentators from Africa, Asia and Latin America advocated the path of Asian Dragons to be emulated [11]. A form of 'Cargo Cult' to emulate East Asian Dragons animated S&T policy slogans in the developing world. Asian Dragons became an important reference point in S&T policy literature.

Myanmar's Sustainable Development Plan 2018–2030 (MSDP), for instance, identifies innovation as an important driver for the 21st century, to catch up with its peers in the region. Interestingly, this country invested just 0.15% of GDP in national R&D and published about 639 S&T publications in 2019. With these indicators, can it *catch up*? Leading French science policy scholars, Jean Jacques Salomon, and Andre Lebeau, cautioned against such erroneous views as early as the 1990s in their book *Mirages of Development*. 'All too often, experts in both North and South assume that the key to development lies in the latest science and technology, despite much evidence to the contrary' [12]. Various versions of 'catch up' and 'late industrialization' strategies proliferated the developing countries. Such S&T policy conceptions begun to assume that countries can build innovation systems or dynamic technological sectors of economy, without paying much attention to professionalized science communities and strengthening science and technology (S&T) systems, including higher educational institutions. With hindsight, we now have systematic evidence to suggest the role of various actors and agencies in STI policies behind the success of national innovation systems or dynamic technological sectors in some Asian Dragons. The main objectives of this paper are listed below. Several issues raised here form different sections of the paper, followed by a concluding section.

(i) In the last two to three decades, why have some developing countries in Asia and Africa progressed through building S&T eco-systems? Why have others lagged behind?
(ii) What is the understanding of innovation and S&T systems? Can we differentiate between countries with dynamic innovation systems from non-dynamic systems of innovation? [13].
(iii) Why could the bulk of Asian and African developing countries not catch up with Asian Dragons in the last couple of decades? To what extent are the Asian Dragon

'models' relevant for agriculture based developing countries, as well as health security? Is basic research, and research-intensive, universities essential factors of development or a luxury for these countries as made out in various policy discourses?

(iv) What are the lessons of learning from the history of S&T policies for development in South Korea, Singapore, China, and India?

(v) Concluding remarks.

2. Methodological Remarks

A social-historical perspective is adopted mainly in this paper which draws on the contemporary history of science, technology, and development perspectives. In doing so, the paper extensively draws on S&T policy analysis and scientometrics data. Much of the data in this paper are also drawn from international agencies, such as UNESCO Science Reports, World Science Reports, World Bank, UNDP, ASEAN secretariat, African Union, and other reliable data bases. Much of the information and analysis is also drawn from secondary sources of published journals, books, and reports. The analysis in this paper is substantiated by various research articles published in *Science, Technology and Society* in the last two decades on African, Latin American, and Asian developing countries. The paper also relied on the field notes and discussions held with various faculty and scientists, science and technology policy scholars and researchers in South Africa, Zambia, Ethiopia, Algeria, Nigeria, Singapore, Vietnam, India, China, Malaysia, Sri Lanka, Indonesia, Cambodia, and Australia over the last two and a half decades. In a large measure, the paper relied on what is known as interpretive sociological method. As Ashley Crossman remarks, 'interpretive sociology is an approach developed by Max Weber that centers on the importance of meaning and action when studying social trends and problems' [14]. It relies on meanings and concepts of people which they attach to their everyday social world. In other words, interpretive sociology basically demonstrates the social reality that is given by people in their everyday life-worlds. The paper relies on both positivist sociology of quantitative data as well as qualitative data which are derived through discussions, interviews and to some extent participant observation in the field.

3. Developing Countries No More Sail in the Same Boat: *'Winners' and 'Laggards'*

The term developing countries, Third World and Global South are employed somewhat synonymously in the UN documents and by the World Bank. With the end of the Cold War in the 1990s, the term Third World gradually disappeared but the other two terms are still in currency. By all means, there was no distinction whatsoever as far as developing countries were concerned. Metaphorically one can say that in the 1970s, developing countries were considered as somewhat homogenous entity and were seen as *sailing in the same boat*. From the perspective of development economics, the major policy concern was how these developing countries as 'laggards' could *catch up* with the 'winners' or industrially advanced developed countries. These latter countries were seen as role models for the growth and progress of developing countries.

Perhaps for the first time the most influential Sussex Manifesto in 1970 drew attention to the significance of the role played by science and technology institutions, technology investments and R&D factors in the process of development of developing countries [15]. In fact, the Manifesto clearly recognized the problems of development based on S&T factors. In a way the Manifesto resonated the views of Homi Bhabha and Abdus Salam. This Manifesto was a draft introductory statement for the 'world plan of action for the application of science and technology to development', prepared by the 'Sussex Group' for the United Nations, Department of Economic and Social Affairs [16].

According to the 1970 Sussex Manifesto, there was no distinction between different developing countries. Almost all the developing countries suffered from low investments in science and technology capabilities. The important recommendation of the 1970s Manifesto recommended that 'the research and development (R and D) effort of the developing countries should be increased from the present level of about 0.2 per cent of gross national product (GNP) to about 0.5 per cent of GNP' [16,17]. Among other important recommendations, the Manifesto called for advanced countries to give liberal aid amounting to 0.05% of their GNP to developing countries R&D [16]. None of the developing countries reached the level of 1% of GDP up to 1980, as pointed out by a leading South Korean economist, Keun Lee. As he further noted, South Korea invested 0.56%; Taiwan invested 0.71%; India invested 0.7%; China invested 0.68%; Nigeria invested 0.3%; Malaysia invested 0.1% and Ghana invested 0.9% of GDP in R&D activities in 1980. 'Korea was in the same predicament as the other developing countries, faced with continual external imbalances and persistent trade deficits during the first two decades of industrialization in the 1960s and 1970s' [18].

The call for increasing the R&D/GDP to 0.5% by the Manifesto resonated quite positively among the decision makers of developing countries in the 1980s. The decades of the 1980s and 1990s clearly demonstrated how the socio-political decisions in S&T policy frameworks made by various countries and policy makers (in South Korea, Taiwan, Singapore, China, Malaysia, and India) begun to set apart some countries from the rest of the developing world. The magic figure of 1% of GDP for gross expenditure in research and development (GERD) recommended by several UN agencies and World Bank documents begun to show up positive indicators by various East Asian Dragons, India, China, Brazil, South Africa, and few other countries by the 1990s. The dissolution of Soviet Union (1988–1991), the dismantling of the Berlin Wall, somewhat coincided with the parallel development of globalization and liberal economic policy regimes in the developing world. For instance, by 1990 China progressed with a decade of liberal post-Mao and Deng reforms, giving a boost to building science and technology infrastructure. Since 1991, the new economic reforms initiated by the Man Mohan Singh government in India also injected a new economic dynamism that enhanced budgets for S&T agencies. In a way, the market failure theories led to the intervention of governments in East Asian countries [17]. While Sanjay Lal from Oxford drew attention through his influential book, *Learning from the Asian Tigers* in 1996, Henry Rowen from Stanford Business School systematically substantiated with fifteen detailed empirical studies on the East Asian Growth [19,20].

By the 1990s it became crystal clear that developing countries *no more sail in the same boat*. There are some *winners* in the sense that some developing countries experienced considerable economic progress compared to other *laggards*. The World Bank published a report on *The East Asian Miracle: Economic Growth and Public Policy* in 1993. The foreword of the report said that 'most of East Asia's extraordinary growth is due to superior accumulation of physical and human capital' [21]. Together with Sanjay Lal and Henry Rowen, leading science policy experts, such as Jean Jacques Salomon and Andre Lebeau in 1993, made explicit that there are '*Many Third Worlds*'. Behind the growth theories projected by economists and World Bank reports, *Asian Miracle* countries made substantial investments in building basic S&T institutional infrastructure and institutional frameworks with appropriate science and technology policies [22]. Some relevant indicators that differentiate different developing countries are presented in Tables 1 and 2. The revised Sussex Manifesto in 2009 that extensively tracked the progress of developing countries since 1970 clearly recognized how a group of developing countries '*jumped over the boat*' [16].

Table 1. S&T and GDP Indicators for Select Countries in Africa.

Country	R&D/GDP %		S&T Publications		GDP by Sector 2018–2021 %			Labour Force by Sector 2018–2021 %		
	Progression from 2000 to 2018		Progression from 1998 to 2019 **		Agriculture	Industry	Services	Agriculture	Industry	Services
Algeria	0.16 (2004)	0.54 (2018)	3263 (2011)	7592 (2019) @	13.3	39.3	47.4	10.8	30.9	58.4
D R Congo	0.08 (2009)	0.41 (2015)	94 (2011)	409 (2019) @	4.9	69.8	25.3	35.4	20.6	44.0
Ethiopia	0.61 (2013)	0.27 (2017)	1321 (2004)	3887 (2019) @	35.5	23.1	36.8	72.7	7.4	19.9
Kenya	0.36 (2007)	0.57 (2017)	456 (1999)	3045 (2019) @	34.5	17.8	47.5	61.0	6.7	32.2
Mozambique	0.42 (2010)	0.33 (2017)	36 (1999) *	460 (2019) @	29.5	23.9	46.5	77.0	8.0	15.0
Madagascar	0.3 (2002)	0.01 (2017)	-	341 (2019) @	26.0	29.0	49.0	63.8	9.1	27.1
Morocco	0.14 (2000)	0.73 (2011)	510 (1999)	7203 (2019) @	14.8	29.1	5.6	39.1	20.3	40.5
Mali	0.66 (2010)	0.3 (2021) #	196 (2011)	302 (2019) @	41.8	18.1	40.5	62.0	7.5	30.0
Nigeria	0.22 (2007)	0.22 (2015)	450 (1999)	9177 (2019) @	21.9	23.6	54.3	30.5	15.0	55.0
Senegal	0.54 (2010)	0.75 (2017)	513 (2011)	749 (2019) @	16.9	24.3	58.8	77.5	22.5	22.5
Sudan	0.22 (2006)	-		1029 (2019) **	39.6	2.6	57.8	80.0	7.0	13.0
Tanzania	0.3 (2000)	0.5 (2013)	196 (2004)	1736 (2019) @	23.4	28.6	47.6	65.0	7.0	28.0
Uganda	0.82 (2000)	0.17 (2018)	-	1731 (2019) @	71.9	4.4	23.7	71.0	7.0	22.0

* https://unesdoc.unesco.org/ark:/48223/pf0000375475.locale=en, accessed on 1 July 2022. ** https://www.scimagojr.com/countryrank.php?year=2019&region=Africa, accessed on 1 July 2022. # https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2021/ml.pdf, accessed on 1 July 2022. @ https://www.unesco.org/reports/science/2021/en/download-report, accessed on 1 July 2022.

Table 2. S&T and GDP Indicators for Select Countries in Asia.

Country	R&D/GDP %		S&T Publications		GDP by Sector 2018–2021 %			Labour Force by Sector 2018–2021 %		
	Progression from 1998 to 2019		Progression from 1998 to 2019		Agriculture	Industry	Services	Agriculture	Industry	Services
Cambodia	-	0.12 (2015)	177 (2011)	439 (2019)	25.3	32.8	41.9	48.7	19.9	31.5
Malaysia	0.22 (1998)	1.04 (2019)	850	30,172 (2019)	8.19	35.9	54.7	10.0	27.0	62.7
Myanmar	0.1 (2000)	0.15 (2019)	155 (2011)	639 (2019)	24.1	35.6	40.3	70.0	7.0	23.0
Nepal	0.05 (2008)	0.30 (2013)	703 (2011)	1665 (2019)	24.5	13.7	61.8	43.0	21.3	35.6
Laos	0.04 (2002)	-	139 (2011)	300 (2019)	20.9	33.2	45.9	73.0	6.1	20.6
Indonesia	0.05 (2001)	0.28 (2019)	446 (1998)	37,513 (2019)	13.7	41.0	45.4	27.7	22.6	49.6
Pakistan	0.63 (2007)	0.20 (2019)	8145 (2011)	21,729 (2019)	23.8	18.9	58.0	37.4	25.4	37.2
Philippines	0.14 (2000)	0.32 (2018) *	371 (1998)	4104 (2019)	7.4	34.0	58.6	22.9	19.1	58.0
Sri Lanka	0.19 (2001)	0.13 (2019)	300 (1999)	2140 (2019)	14.0	26.2	59.2	27.0	26.9	46.0
Bangladesh	0.01 (1997)	0.3 (2015)	2216 (2011)	6362 (2019)	12.9	29.5	53.4	40.6	20.4	39.6
Vietnam	0.19 (2001)	0.53 (2019)	260 (1998)	10,924 (2019)	15.3	33.3	51.3	38.6	26.7	34.7
Thailand	0.19 (2000)	1.14 (2019)	1181 (1998)	17,172 (2019)	8.4	39.2	52.4	31.4	22.8	45.7
Singapore	2.06 (2001)	2.51 (2019)	3004 (1998)	19,437 (2019)	0.5	24.8	75.2	0.7	25.6	73.7

Note: GDP and labour force data taken from Wikipedia * https://www.dost.gov.ph/knowledge-resources/news/72-2021-news/2548-record-breaking-increase-in-r-d-dost-launches-s-t-statistics.html#:~:text=In%20terms%20of%20financial%20resources,its%20corresponding%20gross%20domestic%20product, accessed on 1 July 2022.

Several countries that were 'developing' in 1970 might be considered to have left that category by the later 1990s—e.g., the Newly Industrialized Economies in Asia, and perhaps China . . . One group, the selected Asian NIEs and China had already overshot the Manifesto target by 1990, and massively so by 1999/2000. They accounted for half of the developing countries' share of the global total by 1990, and for two-thirds by the end of the decade.

Behind this path, these countries had GERD/GDP ratios that were about three times higher in 1990 than the Manifesto target of 0.5 per cent for 1980. China was well past it in 1990, and reached 1.0 per cent ten years later. This was an astonishing change given the very rapid growth of GDP during the decade, and it contrasted, for example, with the Indian level that also reached 0.8 per cent by 1990 but stayed roughly constant (0.7–0.8 per cent) through the decade.

However, African R&D is dominated by South Africa which already had a GERD/GDP ratio of 1.0 per cent by 1990—a level it has more or less maintained subsequently. The data for the rest of Africa are especially limited, but they suggest that Sub-Saharan countries and the African Arab states had GERD/GDP ratios of around 0.5 and 0.3 per cent in 1990, but that both groups of countries fell back during the 1990s to the Manifesto's 1970 baseline of 0.2 per cent. [16]

4. Understanding Innovation Systems (Dynamic and Non-Dynamic) and Role of S&T Eco-Systems

4.1. Innovation Systems

In order to fully understand the reasons behind most dynamic innovation systems or East Asian countries, such as South Korea, among others, it is pertinent here to distinguish between innovation systems and S&T eco-systems, although there are institutions and actors which belong to both segments. Innovation may be defined as a new idea, knowledge, and a new way of doing things, which is used by people, markets, firms, or other actors in the production process in a society. According to Schumpeter, we can distinguish five different types of innovation: new products, new methods of production, new sources of supply, the exploitation of new markets and new ways to organize business. Schumpeter (1939) is known for distinguishing between invention and innovation [23]. Invention is associated with novelty or a novel idea, sketch, or model for a new or improved product, process, or system. When an invention finds its application in the market or is used by someone or by an institution, only then can one talk about innovation. Schumpeter basically drew attention to commercial applications of invention to describe innovation. Innovation may be R&D or non-R&D based innovations, such as institutional innovations, organizational innovations, incremental, radical, and technical innovations.

Although the notion of systemic innovation was in vogue in the neo-Schumpeterian and economics literature dealing with innovation, the concept gained prominence with Christopher Freeman (1987) [24], B.A Lundvall (1992) [25] and Richard Nelson (1993) [26]. National Innovation System (NIS) perspectives, as put forward by these scholars, presented a new theoretical grounding to a large number of innovation studies from historical, comparative, macro and micro empirical perspectives since the early 1990s. Freeman (1987:1) defined NIS as a 'network of institutions in the public and private sectors whose activities and interactions initiate, import and diffuse new technologies' [27]. From a broader perspective, Edquist (1997:14) defines NIS as 'all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations' [27]. Universities, together with public R&D labs and government science agencies, public policies (on industry, research, innovation, and higher education, etc.) and business enterprises are now considered as important actors in the NIS. There is also the perspective of Sectoral Systems of Innovation (SSI) which are scaled down versions of NIS. Although NIS and SSI emerged in the context of industrially advanced countries, these perspectives are widely employed for NIEs, Asian Tigers and emerging economies [28]. Franco Malerba defines SSI with three main building blocks, namely knowledge and technology; actors and network; and institutions [29].

4.2. Science and Technology Eco-Systems

S&T eco-systems are composed of five building blocks. (i) The first one is the role of government in scientific and technological strategies, R&D investments, planning processes, coupled with S&T policy regimes. The decision-making systems and the quantum of national GDP/GNP devoted to science and technology and R&D activities play a very crucial role in establishing an institutional base for scientific and technology capabilities. (ii) The second building block involves public and private R&D laboratories. The public R&D labs play a much more important part in developing countries compared to private labs. This is due to market failure factors. Public R&D labs in developing countries also become crucial as research or science in a large measure is a 'consumption factor' and difficult to be taken as an 'investment' factor. It has to cater to the needs and demands of small and medium scale enterprises, science sectors which are related to food and health security, etc. (iii) The third building block includes scientific communities or specialist research groups advancing knowledge. These specialist communities are oriented to strengthen endogenous research capacities and innovation potential.

Scientific communities, particularly professionalized science communities, are invariably integrated with scientific journals and professional societies. These are closely related to the knowledge base and providing intellectual climate in the eco-system as whole. (iv) The fourth building block involves higher educational institutions, including research-intensive universities. These play an important part as frontiers of innovation in the S&T eco-system, wherein most new technologies (biotechnology, nano, new materials, telecommunications, ICTs, etc.) are closely integrated and have their origins and are dependent on science base and new knowledge. In developing countries agriculture universities play a very crucial role. This knowledge base for innovation is increasingly dependent on the research potential of universities and their ability to train and impart skills. (v) The fifth building block is the knowledge base that progresses by output of science and technology in publications, patents, etc.

4.3. Dynamic and Non-Dynamic Innovation Systems

We have seen in the previous section how some developing countries by the 1990s begun to 'jump out of the boat'. By the end of the 1990s, the revised Sussex Manifesto added China, India, South Africa, and Brazil to Asian Tigers, such as South Korea, Singapore, Hong Kong, and Taiwan. We may add more than half a dozen countries, such as Malaysia and Thailand to this list, which have demonstrated considerable progress in endogenous scientific and technological capabilities for development. In an effort to understand the nature of dynamics of innovation learning by countries, one of the leading African S&T policy scholars, Banji Oyelaran-Oyeyinka, in 2006 drew attention to the typology of two groups of developing countries [13]. The first group of countries is characterized as dynamic. Countries in this first group were able to institutionalize a system of learning innovation in development (SLID 1) that emphasizes individual and organizational competence building. Countries in the second group are characterized as non-dynamic as they were slow to learn systems of learning innovation in development (SLID 2). From the perspective of various S&T related indicators, SLID 1 and SLID 2 are differentiated on the basis of investment in R&D, the proportion of technical and scientific human resources, ability at competence building and interaction intensity between different actors in the respective system. Even though Oyelaran-Oyeyinka [13] used the typology to distinguish between East Asian and African countries, by all means one can include other Asian and Latin American countries. Using various authentic research papers and UN agency reports, one can distinguish dynamic and other developing countries between 1990 and 2000 as depicted in Table 3.

Table 3. Dynamic and other developing countries 1990–2010.

Source	Dynamic Countries	Other Developing Countries
Sussex Report 1970	Did not identify any developing country	Developing countries
World Bank 1993 East Asian miracle countries	South Korea, Hong Kong, Singapore and Taiwan	Rest of developing countries
NIEs countries (Wikipedia, World Bank, UNCTAD)	South Africa, Brazil, Mexico, China, India, Indonesia, Malaysia, the Philippines, Thailand and Turkey	Rest of developing countries
Sussex Report 2009 (Revised)	South Africa, India, China and NIEs (South Korea, Hong Kong, Singapore and Taiwan)	Rest of developing countries
Banji Oyelaran-Oyeyinka, 2006 [13]	East Asia Dragons (SLID 1)	African countries fall in SLID 2 (South Africa exception)

5. Insights behind the Success of Dynamic Asian Economies: Three Case Studies

Various influential writings on NIS in developing countries [13,30] robustly project the dynamics of innovation in Asian Tigers, such as South Korea. Several writings have, overtly or covertly, underplayed the significant role played by S&T eco-systems in these countries. In this section, we will select three case studies to demonstrate various elements of S&T eco-systems which are intimately associated with the success of dynamics in innovation, in countries such as South Korea, Singapore, China and India.

5.1. Case Study 1: S&T Eco-System behind the Rise of South Korea

By the time South Korea become a symbol of an East Asian success story in the early 1990s, various metaphors were used, such as 'East Asian Miracle', 'Asian Tiger' and Asian Giant for late industrialization. The main purpose of this short case study is to show that much before South Korea became a part of the East Asian Miracle, the country has established a strong base of an S&T eco-system since the 1960s and particularly from the 1970s. The Ministry of Science and Technology was established in 1967. The three successive Five Year Plans that commenced in 1962 were called so for selective industrialization in chemicals, petrochemicals, iron and steel industries, self-reliance in technology, and building S&T infrastructure. The Korea Institute of Science and Technology (KIST)—a major public research science agency—was established in 1966, which led to spin-off of nearly 20 research institutes (Table 4) [31]. These in turn catered to the technological needs and demands of industries in shipbuilding, petrochemicals, electronics, telecommunications, machinery and energy [32]. In an effort to expand the base of science eco-system, the Park government established the Daedeok Science Town in the Yuseong-gu district in Daejeon in 1973.

As shown in Table 4, over 20 major public research institutes (PRIs) and over 40 corporate research centres make up this science cluster. As Hyung Sup Choi observes, 'DaedeokScience Town is an intellectual complex designed to contribute to the development of science and technology. It is expected that the Science Town will develop as the cradle of Korea's national excellence' [32]. The science town grew out of the research cluster established by the Korea Advanced Institute of Science and Technology (KAIST), which was established in 1971. Basically, KAIST was the higher educational research and training base of Korea in the 1970s and 1980s to meet the human resources demand of various industries. KAIST promoted basic and applied research, PhD training and became a centre of national excellence in advancement of S&T fields. As Keun Lee, Korean economist, observes, 'KAIST has served as a crucial scientific and technological institute by ensuring, with adequate research funding, elite education for the best minds of the country' [18].

Table 4. KIST spin-offs.

Public Research Institutes (PRIs) Type	Spin-off Institutions from KIST
Public Research Institutes	KRISO (Korea Research Institute of Ships and Ocean Engineering) KIOST (Korea Institute of Ocean Science & Technology) KITECH (Korea Institute of Industrial Technology) KIMM (Korea Institute of Machinery & Materials) ETRI (Electronics and Telecommunications Research Institute) KIER (Korea Institute of Energy Research) KOTI (Korea Transport Institute) KISTI (Korea Institute of Science and Technology Information) KRIBB (Korea Research Institute of Bioscience and Biotechnology) KFRI (Korea Food Research Institute) KIT (Korea Institute of Technology) KRICT (Korea Research Institute of Chemical Technology) GTC (Green Technology Center) KERI (Korea Electrotechnology Research Institute) KARI (Korea Aerospace Research Institute) NSRI (National Security Research Institute) KIMS (Korea Institute of Materials Science) KOPRI (Korea Polar Research Institute)
Think Tanks	STEPI (Science and Technology Policy Institute) KISTEP (Korea Institute of S&T Evaluation and Planning)

In an effort to organize finance and investments in R&D and S&T activities, the government established the Korea Technology Development Corporation and the Korea Technology Finance Corporation in the 1970s. According to the figures given by Keun Lee, the country invested no more than 0.42% of GDP in R&D in 1975, which increased more than three times to 1.41% in 1985 and further to 2.37% in 1995, reaching almost 3% of GDP in 2005. One of the remarkable achievements of South Korean S&T policy has been in shifting the national GERD burden towards the private sector from 35% in 1975 to 80% in 1985. The period from the 1980s to the mid-1990s witnessed considerable growth of in-house R&D centres of Korean firms. In an effort to accumulate technological capabilities to gain a share in the international markets in skill intensive industries of electronics and telecommunications, in-house R&D institutes increased from 65 in the 1970s to 183 in 1985 [18].

S&T laws played a significant role in catalysing Korean firms towards promoting in-house R&D by taking advantage of tax incentive schemes. The penal underpinning of such laws directed firms to strictly invest in R&D related activities. As Hyung Sop Choi draws attention, The Law for the Promotion of Technology Development of 1972 provided fiscal and financial incentives; The Engineering Services Promotion Law of 1973 promoted local engineering firms; The Assistance Law for Designated Research Organizations of 1973 furnished legal, financial, and fiscal incentives; and The Law for the Korea Science and Engineering Foundation of 1976 provided a legal basis for the establishment of the Foundation to act as the primary agent for strengthening research in basic and applied science and engineering [30,32].

The field of education at all levels, particularly higher education, expanded in three phases [30]. The first phase was from the 1960s to 1970s. During the Park Chung Hee government, the main slogans were 'nation building through education' and 'education for economic development'. Addressing scientists and engineers in 1966, Park's strategy of utilizing S&T for national building was clearly evident: 'Science-technology is the foundation for increasing productive forces and the source of power for accelerating economic development. It is, in short, a prerequisite and necessary condition for the 'modernization of the fatherland' project' [33]. As an OECD report indicated, the links of education to economic development and economic growth took roots during the Park government. Special emphasis was laid on vocational and technical education [34].

Further, as Kong- Rae Lee points out, there has been an "education fever" of Korean parents to send their children to prestigious universities not only for upgrading their status but also for having better jobs. By 1990, Korea already established 265 universities with 42,911 faculty, which was increased to 432 universities with 84,910 faculty by 2012 [35]. Several research institutes, noted above, also came up during this period. 'More than 35 researchers from KIST became founding members of research centers at private companies, and more than 750 KIST researchers became professors at universities. Thus, through the spillover from the government-established research institutes to the private companies and universities, the research capabilities of private companies and universities were improved' [36].

The second phase can be seen as a transformative phase from the 1980s to 1999. By 1970 the school enrolment as percentage of population reached 100% for elementary level; 99% for middle school; and 86% for high school by 1994. To ensure quality in higher education, the Korean Council of University Education was established in 1982. For tertiary level it increased from a mere 3% in 1953 to around 20% in the 1970s, to registering 49% in 1994. The total number of research scientists witnessed an increase of twelve times (1200%) from 10,300 in 1975 to 132 000 in 1996. In the case of PhDs, the number increased ten times (1000%) from 3417 in 1980 to 36,106 in 1996. Hence, the number of research scientists per 10 000 population increased from 4.8 to 29 for the same period [37]. As Richard Levin, President, Yale University, once remarked, 'in the 1960s, 70s, and 80s, the higher education agenda in Asia's early developers—Japan, South Korea, and Taiwan—was first and foremost to increase the fraction of their populations provided with post-secondary education. Their initial focus was on expanding the number of institutions and their enrolments, and impressive results were achieved' [36]. For instance, university students per 10,000 population of Japan, South Korea and Taiwan were much below the USA and somewhat closer to that of Germany in the 1960s and 1970s. By the mid-1970s South Korea overtook Germany, and by the mid-1990s overtook the USA [36].

In the third phase, the transformation and globalization of higher education began from 1999. The two phases of higher education development, since the 1960s, provided a strong impetus to the professionalization of the science community. The government established the Korean Federation of Science and Technology Societies (KOFST) in 1966 with 71 academic societies and professional organizations. In 1972 the Korean S&T Supporters Association was established. KOFST and its affiliates not only served as a source of intellectual and professional climate to science community in Korea, but more than anything else provided a nationalistic orientation to science. Two KOFST annual resolutions in 1966 and 1986 substantiate this view:

> *We, scientists and engineers, pledge to recognize our duty and the importance of science-technology for 'modernization of the fatherland' and to devote all our energies to the cultivation of science-technology; We, scientists and engineers, pledge to contribute to national economic development by making all our efforts to advance Korean science technology*. [33]

In this phase, the Brain Korea 21 (BK21) project was launched to promote research intensity and innovation in universities. Its main objective was to enhance the global competitiveness of Korean universities. BK21 progressed through three phases, including the project on World Class Universities during 2008 and 2015. During 1999 and 2012, R&D budgets in higher education increased by nearly 300%. The significance of the university's role in Korean innovation systems is clearly spelled out by Kong Rae Lee:

> *The university sector spent approximately 5034 billion KRW in 2011, more than tripled from 1565 billion KRW in 2000. R&D expenditure size of the university sector was smaller that of government research institutes (GRIs) in 2000, but it surpassed that of GRIs in 2005, increasing the gap afterwards. The university accounted for 11.2% out of national total R&D expenditure, 0.2% point lower than that of public research institutes with 11.4% in 2011. It indicates that the university is a major R&D agent of the Korea's NIS, following the government R&D institutes (GRIs) with 10.3% and the*

> *private firms which dominate national R&D activities taking 75.3% out of national total R&D expenditure.* [35]

Given the expansion of higher education in Korea, particularly the university sector, the knowledge base witnessed a dramatic growth for almost two and a half decades between 1990 and 2014. Korea's science output measured by Web of Science stood at 1755 publications in 1990 compared to 15,321 publications of India. South Korean science output witnessed dramatic growth to catch up with India (23 410 publications) at 23,163 publications in 2003. Further in 2014, South Korean science output stood at the level of 55,695 compared with India at 57,543 publications [36]. Similar growth can be seen in the Korean resident patent applications from 1975 when the country registered 1326 resident patents out of total 2914. This figure increased to 2703 resident patents out of total 10 587 in 1985; and 59,236 resident patents out of total 78, 499 in 1995; and resident patents 122, 188 out of total 160 921 in 2005 [20].

The way in which leading South Korean universities boosted the innovation potential of technological giants, such as *Samsung*, is revealed from *Nature's* report of Leigh Dayton. Table 5 shows *Samsung's* ten collaborating academic partners [38]. The firm not only interacted and benefitted from the leading frontier sciences in Ivy Leagues in the USA, but from the leading research-intensive universities within South Korea. As *Nature's* report indicates, 'the company is South Korea's leading corporate institution in the *Nature* Index by far, based on contributions to research articles published in the 82 high-quality natural science journals tracked by the Index. The most productive pairing is with Sungkyunkwan University (SKKU) in Seoul, with 159 joint articles between 2015 and 2019. Their collaboration is particularly strong in electrochemistry and the development of new energy sources such as lithium-ion batteries' [38].

5.2. Case Study 2: Food Security in India and China: Role of S&T Eco-Systems

India and China, as is well known, are the two most populous countries in the world, progressing with over a billion people in each case in the last two to three decades. Despite policy failures leading to food crises and even famines in both the countries before the 1970s, China and India registered tremendous scientific and technological progress in agriculture, resulting in food security and in averting dependence on other foreign countries. By all accounts, both these countries are well recognized for their technological prowess and capacities in agriculture security for meeting food needs of over a billion people in each case. This is to a large extent acknowledged by the most insightful analysis given by Amartya Sen in one of his talks on *Food and Freedom* [39]. What China and India have achieved in food security for their large populations is no less than an 'East Asian Miracle'. Madhur Gautam from the World Bank and Bingxin Yu from the International Food Policy Research Institute in their in-depth comparative empirical study of China and India bring out three important factors for the success of agriculture since the 1980s [40].

Firstly, both countries confronted similar challenges of population and limited land coupled with increasing demand of food security and improved productivity. While India accomplished what has come to be known as the Green Revolution since the 1970s, China reformed its agriculture extensively and comprehensively after 1978: 'In response to surging domestic demand for a more nutritious and high-protein diet, production in high-value sectors like horticulture, livestock, and fisheries has increased in both countries' [40]. Secondly, in agriculture the most impressive record has been in the Total Factor Productivity (TFP) in both countries. Since the 1980s, while China grew at 2%, India grew between 1 and 2%. The results are consistent with other cross-country estimates of TFP growth. 'Agricultural productivity exhibited a continuous upward trend in China, whereas Indian TFP also grew by 1.3–1.7 percent most of the time except for a series of prolonged negative rainfall shocks between 1997 and 2005′ [40]. Thirdly, agriculture in China and India witnessed considerable institutional growth during the 1970s and 1980s. 'Technological advance has been the main source of productivity growth in both countries since 1980. The technology frontier has expanded impressively, averaging 2–3 percent per year in both India and China technological change and accelerating in recent years. The results confirm that investment in agricultural R&D yields very favorable returns over a long period relative to many other types of public expenditure' [40]. The whole issue of technological advance in agriculture draws attention to S&T eco-systems in agriculture in India and China. In fact, the eco-system is the main factor behind the success of agriculture innovation systems in both these countries.

Table 5. Samsung's ten collaborating academic partners.

Rank	Institution	Country	Bilateral Collaboration Score	Count
1	Sungkyunkwan University	South Korea	75.07	159
2	Seoul National University	South Korea	21.10	41
3	Korea Advanced Institute of Science and Technology	South Korea	2016	35
4	Stanford University	United States	19.29	31
5	University of California, Berkeley	United States	17.16	51
6	Korea University	South Korea	13.62	27
7	Yonsei University	South Korea	11.07	22
8	Harvard University	United States	9.67	26
9	Pohang University of Science and Technology	South Korea	8.82	16
10	California Institute of Technology	United States	8.35	12

5.2.1. S&T Eco-System of Indian Agriculture

Even though the Indian Council of Agriculture Research (ICAR) was created under the colonial government in 1929, it continued to relatively stagnate and languish until the 1960s. In 1964, ICAR was a small 'bureaucratized' unit in the Ministry of Agriculture and there was very little connection between the ICAR and the agriculture productive sector, including agriculture extension. From the beginning of the Green Revolution period from the early 1960s, ICAR drew tremendous attention with rapid expansion of its research and extension centres. The budget of ICAR was increased substantially from INR 37 million in 1958 to 183 million in 1970 and further enhanced to 329 million in 1975. There was an almost three-fold increase in ICAR's budget between 1975 and 1981 to about INR 974 million in 1981 [41].

This period also witnessed the establishment of five new agriculture universities and an extension of the existing Indian Agriculture Research Institute, which was revamped with the setting up of a postgraduate school through the assistance of the Rockefeller Foundation on the pattern of the Land Grant College System in the USA. The same pattern was followed in the establishment of new agriculture universities in Uttarakhand, Orissa Punjab, Haryana, Maharashtra, and Andhra Pradesh. The Land Grant pattern entailed a greater concentration of field research in the context of farmers and an extension agency to augment the 'two-way traffic' in applying new S&T inputs to meet the needs of rapidly developing agriculture. Combining teaching, research and extension activities in agriculture universities provided much needed dynamism to the agriculture innovation systems in transferring technologies and knowledge to farmers in the field. The Rockefeller Foundation and the Ford Foundation from USA played an important role in the institutionalization and professionalization of agriculture science in India during the 1970s and 1990s.

Mexican dwarf wheat variety, developed by Nobel Laureate Norman Borlaug, was transferred to India as part of the Green Revolution in the 1960s. These were known as high yielding varieties, but they were adapted to Indian conditions by the agriculture science institutions. Dr M.S.Swaminathan, whose basic research related to the development of potato, wheat, and rice, collaborated with Borlaug in the success of Green Revolution. As Dr B.P. Pal, the head of ICAR, observed, this institution was an 'important agency contributing to the attainment of the green revolution. In fact, the establishment of agricultural universities that made it possible for the ICAR to successfully launch its all-India coordinated projects'. This concept of all-India coordinated projects was, however, developed by the ICAR and this pattern was aligned with the Land Grant pattern in the integration of the Green Revolution. As already noted, ICAR is the apex science agency dealing with research, teaching, and extension of agriculture S&T in the country since the 1950s. It has been an important science agency of the country. Its budget, which was at INR 37 million in 1958–1959 increased to 183 million in 1971; 974 million in 1980–1981; and then to a whopping INR 11,610 million in 2000–2001. In 2017 the ICAR budget stood at INR 53,550 million [41]. There are various institutional and organizational entities which make up for the National Agricultural Research System [42]. This may be depicted in Table 6.

The Green Revolution enabled India to attain self-sufficiency in food grain production by the 1970s. In the dairy milk sector, the White Revolution led by Dr V Kurien enabled India to attain self-sufficiency in milk and associated products by the 1970s. The White Revolution began with the development of cooperatives of farmers involved in milk production. The dairy cooperative network in India comprises 177 milk unions spread over 346 districts, owned by 13.9 million farmer members of village-level societies. The White Revolution involved three policy and programme strategies known as Operation Flood I, II and III between 1970 and 1996. These strategies led to a rapid rise in the formation of more than 75,000 village cooperatives in the 1990s and increased to a whopping 190,000 by 2019. By the 1990s, India became the world's largest milk producer. Dr Kurien and his associates at the Anand Milk Union Limited (the main institution which catalysed the milk cooperatives) resisted several 'internal' and 'external' moves to abort the Indian milk food industry [43]. With the co-operation of the government, particularly Prime Minister Lal Bahadur Shastri, Kurien established the National Dairy Development Board to further strengthen the industrial, trade and research base in the milk sector. Most importantly, India became self-sufficient in food grains, milk, and other agro-industrial sectors—an important national task for a population of India's size. In terms of knowledge base and human capital, the Indian agriculture research system has evolved over the last several decades. However, given the limitations of data and information, only selective indicators are presented in Table 7.

5.2.2. S&T Eco-System of Chinese Agriculture

Over the last two decades, not only has China emerged as world's second largest economy, but the country also witnessed tremendous growth in the agriculture sector. China's success in agriculture productivity, by all means, was driven by its scientific and technological inputs. This became an important reference point for Amartya Sen in analysing Indian agriculture systems since the 1980s. Together with India, China presents us another success story of managing agriculture research and innovation systems in the world. It will be interesting to briefly look into the Chinese agricultural S&T eco-system. About two decades back, in 2002, three leading scholars on agriculture research in China, Shenggen Fan, Keming Qian, and Xiaobo Zhang boasted by observing that 'after 50 years of development, the Chinese agricultural research system is now arguably the largest in the world, employing over 50,000 senior scientists and spending more than US$3.8 billion in 2002′ [44]. They further provided insights and empirical evidence to substantiate the success of Chinese agriculture research systems.

Table 6. National Agricultural Research System, India.

1	Agricultural Universities	There are now 37 Agricultural Universities spread over different states.
2	ICAR Agriculture Institutes	These are: (i) Indian Agricultural Research Institute (IARI), New Delhi; (ii) Indian Veterinary Research Institute (IVRI), Izatnagar; (iii) National Dairy Research Institute (NDRI), Karnal; and (iv) Central Institute of Fisheries Education (CIFE), Mumbai.
3	National Bureaux Institutions	In order to collect, conserve and initiate such measures as would lead to long-term productivity of basic resources, such as plants, animals, fish, microorganisms, soil and water, the ICAR has established five national bureaus: National Bureau of Plant Genetic Resources (NBPGR), New Delhi. National Bureau of Animal Genetic Resources (NBAGR), Karnal. National Bureau of Fish Genetic Resources (NBFGR), Lucknow. National Bureau of Soil Survey & Land Use Planning (NBSS & LUP), Nagpur National Bureau of Agriculturally Important Microorganisms (NBAIM), New Delhi.
4	Central Research Institutes	There are forty-two institutes carrying out basic and applied research on specific crops and transferring the results to the field.
5	Project Directorates	Because of the importance and magnitude of the work involved in a single commodity, such as rice, wheat and poultry, or a group of commodities, such as oilseeds, pulses and vegetables, ICAR has upgraded some of its research infrastructure/projects with added responsibilities, and designated them as Project Directorates. There are eleven Project Directorates.
6	National Research Centers	The National Commission on Agriculture recommended setting up of 'Centers of Fundamental Research' headed by eminent scientists in particular areas. Consequently, the ICAR conceived the idea of setting up a number of National Research Centers. There are 31 National Research Centers
7	All India Coordinated Research Projects	The projects are developed as multidisciplinary and problem-oriented projects with a major emphasis on multi-location testing of new materials/production systems. There are 91 such projects.
8	National Agriculture Research Project	ICAR launched in 1979, with World Bank assistance, a novel scheme known as the National Agricultural Research Project (NARP) to strengthen the regional research capabilities of these universities for conducting need-based, location-specific and production oriented research in identified agro-climatic zones. NARP covers 17 states and Union Territories.
9	National Agriculture Technology Project	With a view to raising the efficiency of resource use for technology generation and assessment as well as transfer, i.e., involving both agricultural research and extension, ICAR initiated the major National Agricultural Technology Project (NATP) in 1998.
10	Technology Missions in Agriculture	The Technology Mission on Oilseeds Research was set up in April 1986, to provide research and technology support to make the country self-reliant in edible and non-edible oils. The Mission concentrated its attention on major oilseed crops, such as groundnut, rapeseed, mustard, soybean, sunflower, safflower, linseed, sesamum, and niger. It also gives priority to non-edible oilseed crops to meet the requirements of industry.

Source: https://aiasa.org.in/wp-content/uploads/2015/07/NARS-India.pdf, accessed on 1 July 2022.

Table 7. Indian agriculture S&T, food grain, and milk production indicators.

	1970	1980	1990	2000	2018
Public funding in Research and Education in Agriculture (INR millions, 1999 prices)	2407 (1961) 7062 (1970)	7118	12,085	22,950	133,110
Enrolment in Agriculutre Higher Education	67,000	96,500	-	107,500	314,000
FTE in R&D in Agriculture	-	19,040	-	-	25,833
PhDs in Agriculture	-	480	690 **	800 ** (1998)	5154
S&T in Agriculture Publications	2036	1975 + 611 *	11,382	12,782 (1998)	69,000 *** (2016)
S&T Journals in Agriculture	159	308 (1978)	327 (1992)	333	-
Foodgrain Production, million tonnes	51 (1950) 108 (1970)	162	176	196	285
Milk production in millions	21.2 (1969)	31.6	55.6 (1991)	78.3	187.7

* 1975 Life sciences and 611 agriculture during 1987–1989 for 3 years; source: *Scientometrics*, Vol. 32, (1) (1995) 11–36. ** Scientometrics, 50(2) 313–321; *** Agriculture, veterinary and biological sciences.

> *Agricultural production has grown at a much faster pace in China than in most other countries for the past 50 years. The yield of rice, the staple of the Chinese diet, has increased from 1.9 tons to 6.3 tons per hectare, a rate of increase of 2.24 percent per year. The yield of wheat, another important crop in China, grew even faster, from 0.6 to 3.9 tons per hectare, or 3.4 percent per year. Overall agricultural production grew by 3.3 percent per year from 1952 to 1997. Growth in grain output and production value has been much higher than the population growth over the same period, so that the amount and value of output per capita has increased. A large proportion of this growth can be attributed to productivity improvement, which in turn comes primarily from new technologies released by the national agricultural research system*. [44]

Chinese agriculture systems involve agriculture research academies, research institutes, agribusiness firms and firms both national and multinational. At the central level research academies and institutes play an important role under the Ministry of Agriculture, while in the provinces, agriculture academies conduct research responding to local and regional circumstances. At the level of prefecture, focus is laid on applied and adaptive research and development. Research at this level is important as prefectures in China are relatively quite large The Chinese Academy of Agriculture Sciences (CAAS),CAAS consists of eight departments, one graduate school, one publishing house, and forty-two institutes in 2008. Between 1994 and 2001, CAAS expanded with around 4989 research professionals and increased in budget allocation from CNY 36.08 to 158.65 million. CAAS research professionals published 2327 articles in 1994, which increased to a total of 21,156 articles in 2001 [44]. According to the CAAS website, the number of research institute remained unchanged at 42, Table 8 shows the growth of agriculture research and other production indicators for 1970 and 2018.

The Chinese Academy of Agriculture Sciences (CAAS), founded in 1957, is the national academy engaged in agricultural R&D, excluding forestry and fisheries. It constitutes the largest and most important institution. CAAS consists of 8 departments, one graduate school, one publishing house and 42 institutes in 2008. During 1994 and 2001, CAAS expanded with around 4989 research professionals and increased in budget allocation from 36.08 to 158.65 million yuan. CAAS research professionals published 2327 articles in 1994 which increased to a total of 21,156 articles in 2001 [44]. According to CAAS website, the number of research institute remained unchanged at 42 currently with 5000 research staff. Presently, 'there are 27 joint laboratories and research centers set up in cooperation with various countries and international organizations and 13 international organizations and foreign agricultural institutions have established liaison offices within the academy. CAAS aligns its research priorities with the so-called Three Rural Issues in China: agriculture, rural community, and farmers' [45]. It currently enrols 4300 students, 65 master and 53 PhD scholars.

Table 8. China's agriculture S&T, food grain and milk production.

	1970	1980	1990	2000	2018
Agriculture Research Funding (1999 prices, CNY million)	630 (1961) 1025 (1970)	2057	2970	5787	-
Enrolment in Agriculture Higher Education	-	-	-	68,966	73,556
Number of Scientists in Agriculture	102,498 (1961–1965)	80,278 (1977–1985)	61,545 (1991–1994)	53,461 (2002)	-
PhDs in Agriculture	-	-	-	2195 (2012)	13,380 (2015)
S&T in Agriculture Publications (CAAS) (JAAS)	-	-	2327 (1994) 778	2668 (2000) 790 (1998)	-
Foodgrain Production, million tonnes	-	304 (1978)	446 (1990)	462 (2000)	618 (2017)
Milk production in millions	-	-	4751	9.2	30.75

Jiangsu is one of the most advanced provinces in China in terms of agricultural production and research. The Jiangsu Academy of Agricultural Science (JAAS, founded in 1932) is the largest of the provincial agricultural academies, with more than 2000 full-time employees in 1998. JAAS has been one of the important actors in the Chinese efforts to reform agricultural research and development system. During the decade between 1988 and 1998, there were 4086 research staff and 1500 support professionals working at JAAS. Core government funding to JAAS witnessed a threefold increase from CNY 9.2 million to 37.7 million; and science output from 546 articles to 652 articles during the same period [45]. In 2018, JAAS has 18 on-campus research institutes, 11 off-campus institutes, 14 international research centres and laboratories, and 26 national laboratories spread over the country [46]. Other key national institutes involved in agriculture related research are the Chinese Academy of Fishery Sciences (CAFS) and the Chinese Academy of Tropical Agricultural Sciences. They report to the Ministry of Agriculture [47]. In 2007, it was reported that this ministry oversees the research activities of 1105 research institutes from different regions of China.

There are about 17 agriculture and forest universities in China. At the national level the three key important universities are China Agriculture University, Nanjing and Central Agriculture Universities. Unlike the Indian case, where the USA land-grant model was adopted in the establishment of agriculture universities, extension is the responsibility of the Department of Agriculture with very little involvement by provincial agricultural universities or academies of agricultural sciences in China. This separation between research, education, and extension has inhibited the integration of technology generation and transfer activities into Chinese agriculture to a large extent [44]. In addition to these institutions in the Chinese agriculture research system, there are development firms owned by agriculture research institutes, agribusiness firms owned by government and shareholder companies which mainly undertake commercial and extension type of activates.

5.3. Case Study 3: Why Singapore Embarked on Building S&T Eco-Systems in the Late 1980s

Singapore's case is exemplary to understand why this small city state begun to build an S&T eco-system, including a professionalized science community, since the 1980s. In fact, Singapore model of development in the 1960s and 1970s was based on developing human capital through skills and taking advantage through developing manufacturing capabilities for Multinational Corporations (MNCs). As early as 1979, the government created the Skills Development Fund and meritocracy remained an important policy measure in jobs [48]. These firms were setting up subsidiaries in Singapore in electronics and textiles due to high labour costs in home economies and due to economic comparative advantage in Southeast Asia in tax incentives. FDI, which stood at S$ 239 million in 1966, increased six times to S$1575 million in 1971 and further to a whopping level of S$ 6349 million in 1979 [49]. Singapore's development strategy involved an export-oriented strategy in the 1970s and hence S&T policy relied on developing skills, adapting technology for exports. The country in fact prioritized education and skills development as soon as it achieved independence from Malaysia in 1959. From a mere S$63 million, the country increased its education budget by 54 times to S$3400 in 1994. Enrolments in educational institutions, at all levels, increased from 353 000 students to 539 000 in 1994 [48,49].

As Govindan Parayil observes, 'the competitiveness of Singapore's economy, despite occasional cyclical downturns, was based on its ability to innovate and learn production and process skills and to leverage MNCs in key industrial clusters' [50]. Around the late 1980s and by the mid-1990s, the Singapore leadership realized that the development model yielded handsome results and prosperity for people but was running out of steam. They also realized that it was unlikely to sustain the comparative advantage in the future. The Economic Development Board (EDB), Ministry of Science and Technology and the political leadership evolved a planning process towards a knowledge based economy for the future of Singapore [50]. The country was already involved in chemicals, electronics, petroleum refining and offshore construction, etc., in the 1990s. The new sectors of knowledge-based economy that the government had promoted since the 1990s are information technology, biomedical, telecommunications, scientific instrumentation, and data analytics. It was indeed a paradigmatic change in the science and technology policy orientation to embark on a journey to generate future wealth from knowledge-based industries. A series of policy instruments were pressed into action from the early 1990s, which allocated appropriate budgets.

EDB established the first ever National Biotechnology Program to venture into biotechnology as a future area of national priority from the late 1980s. In 1990 the government established the National Council for S&T to promote R&D institutions. The National Technology Policy was launched in 1991, which earmarked S$2 billion for research and development. The National Science Technology (NST) Plan instituted in 1991 sought to promote S&T and R&D institutions prioritizing some strategic areas of innovation [51]. A big boost to public policies in science and technology came with the establishment of the National Research Foundation in the Prime Minister's Office in 2006. Over the period of two and half decades, Singapore has had five NST plans, and state support was increased from S$2 billion in the first NST plan (1991–1995) to over eight-fold in the Science, Technology and Enterprise Plan (2011–2015) to S$16.1 billion. The Plan (2011–2015) is uniquely earmarked to create a global nexus of scientific talent by building world-class research infrastructure in Singapore and to scale up the level of science research through innovation. State mediation through initiating science, technology and innovation policies has been a determining factor for the evolution of the Singapore S&T system as it exists today. Singapore increased its R&D as proportion of GDP from a little less than 1.5% in 1996 to 2.2% in 2012. None other neighbouring countries, such as Thailand, Indonesia, the Philippines, and Malaysia could match Singapore in these figures (45). Only Malaysia registered around 1% of GDP for R&D around 2010–2011. The government has officially adopted NIS perspective since the 1990s and invested considerable R&D budgets for promoting S&T eco-system.

Singapore has three major universities: National University of Singapore (NUS), Nanyang Technological University (NTU) and Singapore Management University. In the decade (1997–2007), NUS emerged as a key actor of the national S&T system. The R&D budget of NUS, on average, accounted for around 35% of total higher education R&D budget for the decade 1997–2007. It increased from S$101 million in 2003 to more than threefold to S$366 million in 2007. NUS attracted nearly S$450 million for three major centres of excellence between 2006 and 2009. NUS's contribution to skilled human resources in the tertiary sector has been quite substantial. In the knowledge production, NUS accounted for 45 to 50% of total national R&D output measured in terms of peer reviewed S&T publications for the decade 1997–2013. Singapore emerged as one of the lead science producing countries in the ASEAN region [51].

In 1980 Singapore published 258 science publications measured in terms of Science Citation Index—Expanded Version, compared to Malaysia (452); Thailand (457); the Philippines (241); and Indonesia (182). In little more than two and a half decades, Singapore leapfrogged, leaving its ASEAN neighbours far behind. In fact, Singapore's international peer reviewed publications surged by 214% during the period, from 3963 in 2000 to 12,440 in 2014. The Times Higher Education of world class rankings put NUS at 21st position in 2014 among the top 50 world class universities. NUS currently enrols about 38,000 students and has 2314 faculty, with at least 45% from foreign countries [51]. Similar is the significance of Nanyang Technological University, which ranked 20th in the QS world rankings. It has 34,384 enrolled students and 7613 faculty and staff as of 2021.

NUS established about 20 research institutes and centres in natural, physical, engineering, and social sciences from solar energy, digital media, tropical medicine, and marine studies to specialised research institutes in different regions of Asia. About 500 full time research scientists and fellows, including visiting scholars, are engaged in research in these university levels, research institutes and centres. *Biopolis* is generally referred to as Singapore's biomedical cluster that fosters a collaborative culture among the private and public research community. Establishing this cluster of labs in 2003 was an important milestone for the emergence of the Singapore science community. *Biopolis* houses some eight national laboratories engaged in biomedical related R&D activities. Some indicators are given in Table 9 [51]. *Fusionopolis*, another cluster, brings together engineers and technology experts from the public labs of the Agency for Science, Technology and Research (A*STAR) and those from the private sector. They share the common goal of advancing technology in a number of research programs. There are five leading national laboratories here in engineering, chemical information, and media technology.

From the 1970s, the government begun to develop Science Parks. 'The park is built on an idea where science, innovation, and technology would be seamlessly integrated together. The park drew its inspiration from similar parks in Japan, Taiwan, South Korea and England, and modeled after R&D complexes at Stanford University and Massachusetts Institute of Technology' [52]. The three science parks house some 350 to 375 firms and institutions, including some 200 registered firms with R&D facilities. Singapore science parks provide high-quality R&D infrastructure with a close proximity to NUS. There are a number of collaborative projects between NUS and laboratories located in three science parks. Research students are involved in joint projects and pursuing PhD projects. They also share research facilities, seminars and workshops, access to the library and other person-to-person-based communications which enhance the research.

In about two decades since 1990, Singapore established a very dynamic S&T ecosystem relative to its size, with world class universities, public and private research laboratories, science parks and attracted a steady stream of global talents in science, engineering, and information technology fields. 'Singapore has made an asset of its smallness', as the *Science* journal from the American Association for the Advancement of Science once commented, in bringing together a 'critical mass' of scientific talents and resources. Above all, Singapore was able to build a vibrant national science community in biological and life sciences. Science output of Singapore increased 38 fold from a mere 258 articles in 1980 to a whopping 9925 articles in 2010 [51]. By all means, Singapore clearly demonstrates an exemplary case to show how critical it is to build a base in S&T eco-systems and a professionalized science community to derive benefits towards a knowledge-based economy.

Table 9. Major research institutes at *Biopolis*, Singapore.

Institutes	Year of Established	Total Strength	Main Area of Focus
Bioinformatics Institute (BII)	2007	96	Research focus centres around knowledge gained from biological data, exploiting high-end computing in biomedicine, advancing molecular imaging of biological processes, modelling of drug design and delivery, computational proteomics and systems biology.
Bioprocessing Technology Institute (BTI)	2003	56	Expertise in bioprocess science and engineering.
Genome Institute of Singapore (GIS)	2003	300	The integration of technology, genetics and biology towards the goal of individualized medicine with emphasis on cancer biology, pharmacogenomics, stem cell biology and infectious disease.
Institute of Bioengineering and Nanotechnology (IBN)	2003	180	Focuses on research at the interface of bioengineering and nanotechnology in the areas of nanobiotechnology, delivery of drugs, genes and proteins, tissue engineering, artificial organs and implants, medical devices, as well as biological and biomedical imaging.
Institute of Medical Biology (IMB) ***	2007	133	To conduct research activities in areas such as stem cells, development and differentiation, skin biology, cancer and genetic diseases.
Institute of Molecular and Cell Biology (IMCB) ****	2004	62	Conduct research in cancer, structural biology, drug discovery, stem cell genetics, cell biology in heath and disease.

*** IMB Center for Molecular Medicine (CMM) reconstituted as IMB in 2007. **** IMCB setup in 1985 and moved to Biopolis as autonomous research institute in 2004. Source: Compilation by authors from respective websites of research institutes at Biopolis accessed during 21-12-2014–20-01-2015.

6. Concluding Remarks: Implications for Developing Countries

6.1. No More Sailing in the Same Boat

Historical perspective combined with science and technology policy analysis, in this paper, has thrown up several lessons of learning for developing countries. In 1970, when world leading science policy experts produced the famous Sussex Manifesto, all the developing countries were *sailing in the same boat*. In two decades, by 1989, the World Bank, UN Agencies and leading experts mustered enormous empirical evidence to suggest that Asian Dragons, such as South Korea, Hong Kong, Singapore, and Taiwan, had transitioned through dynamic technological capabilities. Hence, *they no more sail in the same boat*. As the world progressed into the 1990s, the term of NIEs came into prominence by naming countries, such Turkey, China, India, Mexico, Brazil, South Africa, and Malaysia, prominently in the literature. In 2003 a Goldman Sachs report coined the term BRICS, which included Brazil, Russia, India, China, and South Africa. It began the report by commenting that 'between 2000 and 2009, the pace of growth of emerging economies outpaced that of developed countries for the first time. They could become a much larger force in the world economy' [53]. The revised Sussex Manifesto, published in 2009, identified several countries which seem to have *jumped out of the boat*. In fact, this Manifesto clearly distinguished countries which have surged ahead and those which were still lagging behind and struggling to *catch up*.

In 2010, twenty-five leading scholars working on NIS and development economics led by Beng-Ake Lundvall pro-actively recommended NIS perspectives in their *Handbook of Innovation Systems and Developing Countries* [28]. As Rob Hagendijk points out, the handbook contained several useful insights on the 'notion of innovation as society wide learning' and 'focuses on capability building, public policy and institution building, indigenous knowledge, participation, investments in inclusive education and health policies' [54]. However, the handbook included emerging economies and middle income countries in Latin America but did not include innovation systems in the African continent [55]. This raises an important issue whether NIS perspectives are relevant and useful as S&T policy agendas for several African and small Asian countries. This is particularly so when several of these countries are investing less than 0.3% of GDP to R&D, and S&T infrastructure is relatively weak to compliment innovation strategies.

At the same time, although implied in varying ways, the handbook did not tell us *why some developing countries were able to jump off the boat* and evolve dynamic innovation systems and *why others failed to do so*? This is where Oyelaran-Oyeyinka's influential paper comes in, that clearly distinguishes between dynamic East Asian countries and non-dynamic developing countries [13]. Despite very useful concepts and insights on interactive learning and capability building approaches, studies on NIS underplayed the importance of S&T eco-systems, particularly, the critical role of professionalized science communities, research-intensive universities and the significance of basic research in developing countries. This paper makes an attempt at looking back into the historical background of three case studies (South Korea, Singapore, China, and India) to assess the significance of S&T eco-systems. As it turns out, these case studies not only raise some implications for developing countries in Africa and Asia but also throw up some important lessons of learning.

6.2. Difficult to Build and Embark on Dynamic Innovation Systems with Weak S&T Eco-Systems

The two case studies of South Korea and Singapore have thrown ample light on S&T policy insight that *there is no shortcut either to development* or *building a viable S&T eco-system*. In the case of Korea, Hyung Sup Choi, President of KIST (1961–1971) and a Minister of Science and Technology (1971–1978) in 1966 clearly spelled out the government strategy of utilizing S&T for national building. As South Korea was reeling under poverty and suffering from underdevelopment in the 1960s, he said, 'the fundamental reason we are backward in scientific civilization is that our ancestors fifty, even twenty years ago, being overawed by advanced scientific civilizations at the time, gave up and wasted their time without making any effort to improve and develop. Science-technology is the foundation for increasing productive forces and the source of power for accelerating economic development. It is, in short, a prerequisite and necessary condition for the 'modernization of the fatherland' project' [33,56]. As the case study shows, Korea systematically went on to build a vibrant S&T eco-system for two decades, from the 1960s to the 1980s, registering an impressive figure of R&D/GDP from 0.42% in 1975 to 1.41% in 1985. This is much before the World Bank called it an 'East Asian Miracle' and Sanjay Lall included Korea in the list of 'Asian Tigers'. What Korea achieved during the 1960s and 1980s leaves an important historical lesson to developing countries.

The development economics and S&T policy literature, in a large measure, focuses on post-1990s South Korean technological innovation in relatively glaring terms. However, only a residual attention is paid on the role played by state mediation in education at all levels and the role of public research labs (KIST for example) and universities in laying the foundation of an S&T eco-system. When markets and international technology transfer fails to infuse dynamism, public policies and government must assume a leading role. Even a cursory look into developing countries which have made relentless efforts in *catching up* in the last two decades makes the point little clearer. Malaysia and Thailand in 2019 registered R&D/GDP levels beyond 1% compared with less than 0.2% two decades back in 1999. This investment in building R&D and S&T institutions led Malaysia with a potential knowledge base of S&T publications. It was at the level of 850 publications in 1998 and registered an impressive 30,172 in 2019. A similar trend can be seen in Thailand's science output, which increased from 1181 in 1998 to 17,172 in 2019.

As Tables 1 and 2 show, Vietnam, Algeria, Morocco, Kenya, Ethiopia, and Nigeria have begun to invest above the levels of 0.5% of GDP in R&D in 2019 and have shown some noticeable progress in their respective science output, ranging from 10,924 publications in the case of Vietnam to 3887 in the case of Ethiopia. This is where UNESCO's recommendation of 1% of GDP for R&D activities at the national level for developing countries assumes enormous significance. Looking back into South Korea, it must be clear to policy makers in developing countries that there is no *short cut to development* other than turning attention to the basic building blocks of an S&T eco-system. This is particularly so in the contemporary phase of the fourth Industrial Revolution, when countries are reimagining the old Baconian idea of *knowledge is power*. The Singapore case makes the point a little clearer that a comparative advantage in building a knowledge-based economy relies heavily on a strong base of a science and technology eco-system.

6.3. S&T Eco-System Is an Important Building Block for a Knowledge-Based Economy

Singapore was a thriving economy in the mid-1980s when the country embarked on the path towards building a knowledge-based economy. From 1986 to the early 1990s, Singapore's Economic Development Board recurrently begun to assess its future economic prospects. The government realized that 'Singapore needed to find a new niche because its niche as offshore production centre for the developed world would have eroded by the 1990s' [57]. Following the OECD report of 1996, the government realized that in the knowledge-based economy, production, distribution and use of knowledge and human skills are the main drivers of growth, wealth generation and employment for new emerging knowledge-based industries [58]. In the new paradigm of the knowledge-based economy, as the former Prime Minister, Goh Chok Tong envisioned, 'objective was to *reinvent Singapore* as a *learning nation* such that the *spirit of innovation* would *permeate every level and sphere of society*' [50].

In many ways, the leadership anticipated that Singapore will not be able to maintain its economic growth and global competitiveness without developing a strong S&T eco-system. Singapore embarked on basic building blocks of an S&T eco-system and science community from the 1990s to develop innovation potential and human skills for the emerging knowledge-based economy in 2000 and anticipated the challenges of the fourth Industrial Revolution. As Calestous Juma, Harvard science policy scholar observes, 'Singapore's lessons for other developing countries have yet to be fully appreciated. How to reform educational systems to keep pace with contemporary challenges is one the most important leadership lessons that developing countries can learn from Singapore. Lee Kuan Yew emphasizes his belief in the supremacy of the quality of human capital. He emphasizes the importance of knowledge in economic transformation' [59]. Singapore's S&T policy efforts on building *Biopolis* since the 1990s throws up another important lesson for developing countries on basic research.

6.4. Basic Research Is Not a Luxury but an Essential Factor in the Process of Development

The objective of briefly exploring the case of agriculture security in India and China was to show that oriented basic research (not fundamental research) is not a luxury but an essential factor in the process of development. It was a conscious political decision, on the part of India and China in the 1960s, to embark on building a strong base in agriculture research systems and indigenous agriculture science communities. Given large populations in each case, agriculture security was paramount to both governments which evolved two diverse political and economic systems. This is an important lesson that these two large economies throw up for developing countries in Asia, Africa, and Latin America. In the last half a century, both these large countries were self-sufficient in food grain production. Self-reliance in agriculture science and technology was the cornerstone of S&T policy even when there was technology transfer and adoption of foreign models, such as the land-grant universities in the Indian case. What is the meaning of establishing technological capacities for agriculture security in India and China?

The answer to this question leads us to oriented basic research capacities in entomology, plant physiology, biotechnology, chemistry, soil science, water technology, fisheries, and aquaculture, etc. Equally important and crucial are agriculture universities, including extension centres, professionalized societies, and journals, including various institutional structures which go with the concept of S&T eco-systems. In about two dozen countries in Asia and Africa (See Tables 1 and 2), one can see that predominant proportion of their GDP and labour force are dependent on agriculture and allied activities. However, a large number of developing countries are still agrarian societies and food security is a very important economic factor. One may add health security and the increasing importance of biological and life sciences to agriculture sciences. It is doubtful that post-2000 Asian Tigers, such as South Korea, provide a relevant national 'model' for development, although some sectors of economy may provide lessons of learning. *There is no short cut to development* here other than establishing endogenous science capacities in agriculture, health, and biological sciences in developing countries. Equally crucial is the role of government and national leadership as big foreign firms are unlikely to show interest in tropical agriculture and tropical diseases which have limited scope for spinning out profits from commercial operations. Indian agricultural research system clearly demonstrates that foreign models and technology transfer become relevant only when there is sufficient endogenous S&T capacity to absorb and innovate, keeping local conditions in perspective.

Funding: This paper was presented as a keynote speech at SOI 2022, and the publishing fee was supported by SOI.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: Some material and portions of the paper were drawn from the author's own research and earlier research papers and books. These are fully acknowledged and there is no conflict of interest in this regard.

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