The Efficiency of R&D Expenditures in ASEAN Countries

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Abstract: The aim of this study is to determine whether funds spent on research and development are used efficiently in Association of Southeast Asian Nations (ASEAN) countries. Fifteen countries in the 2000-2016 period have been examined. Measuring the efficiency of research and development spending was performed using the non-parametric Data Envelopment Analysis (DEA) methodology, which allows for the assessment of input–output efficiency. The research includes the following input and output variables: annual public and private spending on innovation, high-technology exports as a percentage of manufactured exports, patent applications to the World Intellectual Property Organisation (WIPO) by priority year for million inhabitants, trademark applications (TA) for million inhabitants and information and communications technology (ICT) exports as a percentage of manufactured exports. Hong Kong and the Philippines are perhaps the most efficient with respect to research and development (R&D) when analysed using the constant return to scale (CRS) approach. However, according to the variable return to scale (VRS) approach, the most efficient ASEAN countries are Hong Kong, Indonesia, Singapore and the Philippines. The study also confirms that increased spending on innovation is resulting in non-proportional effects.

Keywords: Innovation; DEA Methodology; Relative efficiency

1. Introduction

The importance of innovation in shaping economic growth is fundamental to new growth theory, which assumes that long-term growth can be achieved through endogenous technological progress [1]. This theoretical concept has been confirmed in numerous empirical studies [2–5]. Improving innovation is particularly important for developing countries that are trying to improve their competitiveness and stimulate economic growth. As concluded in the study of Liu et Al. [6], the whole world is benefitting from the R&D inputs of advanced countries and international R&D spillovers help to improve technologies, but at the same time the worldwide technological gap is still enlarging.

Nowadays, governments focus on the development of innovation policies and strategies. This strategy assumes a steady increase in R&D spending; however, such spending does not necessarily go hand-in-hand with the efficient use of such funding. Such inefficiency may be one of the reasons for the deepening innovation gap.

The Association of Southeast Asian Nations (ASEAN) countries were selected for this analysis due to the dynamic growth of the region. Ten countries belonging to the ASEAN group are characterised by a wide variety of macroeconomic indicators, levels of development and innovation. Also, the experience of ASEAN countries in the areas of shaping and conducting innovation policies and creating national innovation systems are diverse.
Despite over 40 years of cooperation among ASEAN member states (AMS) in the fields of science, technology and innovation (STI), little has been achieved in the establishment of a region-wide innovation policy. Notwithstanding this, there have been many important initiatives at the regional level aimed at enhancing the innovation capacities of AMS. In 1978, the ASEAN Committee on Science and Technology (ASEAN COST) was established to promote and coordinate STI and human resource development policies across ASEAN, as well as to stimulate the intra- and extra-ASEAN transfer of technologies. Such technological transfer has been inscribed in the institutional framework of ASEAN summits and the ASEAN Ministerial Meetings on Science and Technology (AMMST). Both AMMST and ASEAN COST meet yearly to address STI policy issues, with the latter regularly hosting representatives of the European Union, China, Japan, South Korea and the United States. ASEAN COST has been instrumental in spearheading the creation of the first ASEAN Plan of Action on Science and Technology in 1985. At the second ASEAN Informal Summit on 15 December 1997 in Kuala Lumpur, the ASEAN Vision 2020 was announced, which pointed to STI policies as one of the pillars of a future technologically competitive ASEAN, with highly skilled workers and strong networks of R&D institutes. Shortly after the establishment of the ASEAN Economic Community (AEC) in December 2015, the ASEAN Plan of Action on Science, Technology and Innovation 2016–2025 was announced to promote an innovative, competitive, integrated and sustainable ASEAN by 2025. A set of strategic actions was aimed, among other things, at promoting cooperation between the public and private sector, small and medium entrepreneurship, skilled staff mobility, the transfer of R&D results and commercialisation. ASEAN COST has subsequently been relocated from the ASEAN Socio-Cultural Community (ASCC) to the AEC Blueprint 2025, thus stressing the role of innovation, investment in R&D and STI in improving productivity and industrial competitiveness of ASEAN. However, ASC Blueprint 2025 still addresses STI in the field of education to establish a creative, innovative and responsive ASEAN.

The aim of this research is to verify whether funds spent on R&D are used efficiently in ASEAN countries. Innovativeness is a popular topic discussed in numerous scientific articles, where it is studied through the prism of expenditure, its effects and innovation policy. However, the efficiency of R&D spending, while seldom addressed, is certainly worth exploring.

The rest of the paper is organised as follows. Section 2 presents a review of the literature regarding innovation policies in the ASEAN region and investigates innovation efficiency across ASEAN. Section 3 presents the research methodology. Section 4 describes the results of the data, while we discusses the meaning of these results in Section 5. Section 6 concludes this research.

2. Literature Review

2.1. Region-Wide Innovation Policy in ASEAN

To date, there have been few in-depth studies of innovation policies in ASEAN or their economic impacts. These studies include analyses by the Economic Research Institute for ASEAN and East Asia (ERIA). Hahn and Narjoko [7] studied innovation at the level of microenterprises and establishment in East Asian countries. Kuncoro [8] conducted research on innovation among medium and large enterprises in Indonesia under globalisation, finding a disorganised approach to R&D expenditure in the private sector between the mid-1990s and mid-2000s, with R&D declining in years 2000–2006. Ito [9] observed that many enterprises in Indonesia shifted from high-end to low-end products, which would suggest that the assumption of increased R&D expenditure and innovation might be inaccurate. Indonesia, like many AMS, has been challenged by the middle-income trap due to a development strategy relying on their cost advantage in the labour-intensive manufacturing/industrial market [10]. As argued by Ambashi et al. [11], the rapid rise in the cost of energy and related commodities upon which primary industries depend at the beginning of the 21st century has discouraged private sector innovation in many AMS and has led manufacturers to avoid high-end products. In this regard, there
is a lack of incentive to spend on R&D and innovation in the long run by both public and private sectors in many AMS [9].

The Global Innovation Index 2019 rankings recognise eight AMS among 129 countries/economies (except Lao PDR and Myanmar), with Singapore in the highest rated (8th) position, followed by Malaysia, Vietnam, Thailand, the Philippines, Brunei Darussalam, Indonesia and Cambodia (in 35th, 42nd, 43rd, 54th, 71st, 85th and 98th positions, respectively). Malaysia was ranked second after China in the upper-middle income group, and Vietnam first in the lower-middle income group. Noteworthy, Singapore was ranked first in the Innovation Input Sub-Index 2019, surpassing, among others, Switzerland, the United States and the Scandinavian countries; however, with respect to the Innovation Output Sub-Index 2019, Singapore was only ranked in the 15th position. Noteworthy, South East Asia is described as a region of continuous improvement in innovation.

The United Nations Development Program (UNDP) assessed AMS in terms of the Technology Achievement Index (TAI), recognising an increase in regards to technological development and innovation in 1999–2008 in Brunei Darussalam, Malaysia, Singapore, Thailand, but especially in Vietnam. The Asian Development Bank Institute divided AMS into two categories in terms of technological and innovation capacities based on data from 1999 to 2008: Singapore as the frontier and the rest of AMS. Interestingly, while Singapore’s performance proved to be comparable to that of Japan and South Korea, followers were ranked similarly to China and India.

Ambashi et al. [11] stressed that ASEAN as a whole is characterised by economic growth, surpassing the technological and innovation achievements of most individual AMS. Intal et al. [12] categorised these AMS into five groups, taking into account their stages of innovation (Table 1).

Intal et al. [12], building upon the work of Rasiah [13], studied the innovation policies of AMS in regards to basic and high-tech infrastructure, network cohesion and global integration. Less developed AMS (e.g., Cambodia, Lao PDR and Myanmar) are encouraged to stabilise politically, inspire demand for innovation, competition and openness to foreign markets. Indonesia, the Philippines, Thailand and Vietnam—classified to learning phase—are expected to learn-by-doing and to imitate, advance social institutions to play the role of formal intermediaries between economic agents, and to be open to foreign markets and foreign direct investment (FDI). As argued by Ambashi et al. [11], AMS might establish and develop their own national innovation system (NIS) based on the typology described above, taking into account various capabilities and limitations. A multidimensional approach to innovation policy could embrace both industrial and trade policy measures, R&D expenditure and incentives, as well as human resources development. Importantly, the national governments of AMS may consider seek for balance between market and non-market mechanisms of intervention to proceed with innovation-based industrialisation. In this regard, ASEAN as a whole might consider to work on a region-wide innovation policy that would induce synergy between the innovation policies of AMS.
### Table 1. Typology of innovation policies in AMS.

| Phase | Basic Infrastructure | High-Tech Infrastructure | Network Cohesion | Global Integration |
|-------|----------------------|--------------------------|------------------|--------------------|
| (1) Initial conditions | Cambodia, Lao PDR, Myanmar | Political stability and efficient basic structure | Emergence of demand for technology | Social bonds driven by the spirit to compete and achieve | Linking with regional and global markets |
| (2) Learning | Thailand, Philippines, Indonesia, Vietnam | Strengthening of basic infrastructure with better customs and bureaucratic coordination | Learning-by-doing and imitation | Expansion of tacitly occurring social institutions to formal intermediary organisations to stimulate connections and coordination between economic agents | Access to foreign sources of knowledge, imports of material and capital goods, and inflows of foreign direct investmentIntegration in global value chain |
| (3) Catch-up | Malaysia | Smooth links between economic agents | Creative destruction activities start through imports of machinery and equipment, licensing, and creative duplication | Participation of intermediary and government organisations in coordinating technology inflows, initiation of commercially viable R&D | Licensing and acquisition of foreign capabilities, upgrading synergies through technology imports, emergence of strong technology-based exports |
| (4) Advanced | Advanced infrastructure to support meeting demands of economic agents | Developmental research to accelerate creative destruction activities. Frequent filing of patents in the United States starts | Strong participation of intermediary and government organisations in coordinating technology inflows, initiation of commercially viable R&D | Access to foreign human capital, knowledge links, and competitiveness in high-tech products and collaboration with R&D institutions |
| (5) Frontier | Singapore | Novel infrastructure developed to save resource costs and stimulate short lead times | Basic research R&D labs to support creative accumulation activities generating knowledge. Technology shapers generate invention and design patents extensively | Participation of intermediary organisations in two-way flows of knowledge between producers and users | Connecting to frontier nodes of knowledge, and competitive exports of high-tech products |

Sources: [11,12].
Both Japan and South Korea are examples of countries that have successfully established their NIS and developed domestic innovation with the support of properly designed industrial and trade policies, relying on strategic technological and knowledge resources imported from the Western economies [14]. In the case of Japan, licensing agreements, strategic alliances with Western businesses as well as reverse engineering have played a crucial role in their NIS. Using highly-skilled low-wage human resources, Japanese enterprises imitated Western products to create something new and unique as opposed to relying on the transfer of foreign technologies and knowledge through FDI, as has been the case in China and Singapore. Domestic industries were supported by the government through R&D and export incentive schemes. Similarly, instead of relying on inward FDI, South Korea developed an industrial policy aimed at the effective use of licensing agreements and arm’s length connections with Western enterprises to build domestic innovation capacities, with strategic support dedicated to large business conglomerates. China’s NIS has relied heavily on technology transfer through FDI since the late 1970s, attracting Western businesses with a network of economic and technological development zones supported by industrial policies and export promotion. Both central and local governments enhanced the development of industrial clusters through regulatory reforms, financial incentives and networking between SMEs, research institutes and universities [12]. In relation to China, India demonstrates relatively low manufacturing and innovation competitiveness, thus its innovation ecosystem has made less progress in such aspects as innovation and business sophistication and higher education. Inadequate R&D expenditure—far below the target of 2% of GDP set in 2013—has been dominated by the public sector, with special regard to the central government. On the other hand, while the private sector remains relatively active in R&D activities in pharmaceuticals, information and communications technology (ICT) and transportation, it is still only a relatively minor contributor [15]. Since the 1980s, India has attempted to become a kind of software hub, capitalising upon the prior success of South Korea and Taiwan. In 1990, the government established the Software Technology Parks (STPs), where Indian enterprises pioneered a Global Offshore Delivery Model.

2.2. National Innovation Policies in ASEAN

To date, six AMS have established NIS, categorised either to frontier phase of innovation policy (Singapore), catch-up phase (Malaysia) or learning phase (Indonesia, the Philippines, Thailand and Vietnam).

2.2.1. Indonesia

Indonesia has moved toward a service-led and knowledge-based economy since the mid-2000s. Previously, however, Indonesia’s development strategy and economic growth used to rely heavily on natural resources and trade in the import-substitution industries, followed by the accumulation of labour and capital instead of science and technology. Key challenges included institutional and regulatory bottlenecks, as well as a deficit of highly-skilled workers. Importantly, both public and private R&D expenditure was government-centric and far below the average for the lower-middle income transitional economies. As observed by Ambashi et al. [11], foreign enterprises are discouraged from conducting R&D activities in Indonesia due to the relatively low quality of intellectual property rights (IPR) with no significant changes in this regard after 2010.

In 2010, the National Innovation Committee was established to make innovation policy more systematic and better governed; however, it was very soon dissolved under the guise of streamlining bureaucracy. The coordinating role of the Directorate General for Innovation Strengthening, under the supervision of the Ministry of Research, Technology and Higher Education (MRTHE), is highly questionable due to lack of political mandate in multilayered hierarchy. Despite the government-centric character of Indonesian R&D projects, they were historically poorly coordinated and short-lived because of a lack of any formal, integrated NIS with no governing framework. Indonesia’s NIS (SINAS), which is still under implementation, was established on the basis of the Medium-Term Development
Plan 2015–2019, which aimed to increase Indonesia’s capacities in STI. This initiative should be regarded as a step toward the implementation of more effective and formal innovation system.

2.2.2. Malaysia

In Malaysia, dynamic economic growth and technological development has been enhanced since the 1980s by inward FDI, moving this economy up in the value chain from primary to manufacturing products. Among key documents addressing science, technology and innovation development at both macro and micro level, there has been the First National Science and Technology Policy (NSTP1) 1986–1989; the Industrial Technology Development: A National Action Plan 1990–2001; Second National Science and Technology Policy (NSTP2) 2002–2010; and National Policy on Science, Technology and Innovation, 2013–2020. Among the key objectives of the strategies were enhancing national R&D capacities, the commercialisation of R&D results through the National Innovation Model, establishing partnerships between public universities and industries, and the development of new knowledge-based industries.

The Malaysian government failed to achieve two of the basic objectives of the NSTP2, assuming an increase in R&D expenditure (up to 1.5% of GDP) and personnel (up to 60 per 10,000 inhabitants) by 2010. The National Policy on Science, Technology and Innovation, 2013–2020 put an emphasis on sharing and communicating the objectives of STI policies among stakeholders, enhancing R&D capacities of both public and private sectors, and promoting good governance to secure high quality institutional and regulatory framework of STI. The New Economic Model (NEM), announced in 2010, emphasised innovation. The NEM (2010) departed from the strategy of manufacturing export based on low-cost labour immigration in favour of domestically-developed innovation capacities.

The Malaysian NIS has evolved gradually, with the Ministry of Science, Technology and Innovation (MOSTI) and Ministry of Higher Education (MOHE) playing key roles. MOSTI supervises several entities involved in biotechnology, ICT, industry, sea-to-space as well as ST, such as National Institutes of Biotechnology Malaysia (NIBM) and Academy of Sciences (ASM), while MOHE governs a network of centres of excellence with solid international reputation, mainly thanks to research results and publications [16]. Both MOSTI and MOHE are primary donors to R&D activities in public and private sector, however, other ministries such as Ministry of International Trade and Industry, Ministry of Energy, Green Technology and Water, the Ministry of Agriculture and Agro-based Industry, and the Ministry of Finance provide financing schemes to selected stakeholders.

As already noted, Malaysia is currently in the catching-up phase, thus still needs to improve and advance its NIS to follow frontiers, such as Singapore. Firstly, there is a need to consolidate the numerous departments, agencies and institutes inside the NIS to avoid overlaps and to make interconnections between the different schemes and initiatives, making these clearer and more transparent. Secondly, the availability of R&D incentives for industry are limited because of the administrative burden and information deficit. Thirdly, universities could be more active in knowledge transfer, spill-over and dissemination, and thus be more flexible and open to various stakeholders. Fourth, the number of patent applications might be increased, including involvement of SMEs and better IP governance.

2.2.3. The Philippines

The Philippines had no emphasis on innovation policy until the late 2000s; however, many STI plans and projects were launched following 1993 under the Ramos administration. The first National Innovation Strategy (2000–2010), or Filipinnovation, was focused on investment in human capital, STI and related management systems, and upgrading the Filipino mindset. There were four strategies in the Philippine Development Plan 2011–2016 aimed at making national industries and services sectors globally competitive and innovative. The Duterte administration (2016–2022) implemented a strategy of promoting and increasing innovation under four national programs: the Collaborative Research and Development to Leverage Philippine Economy Program (CRADLE), the Niche Centers in the Regions
for R&D Program (NICER), the R&D Leadership Program (RDLead) and the Business Innovation through S&T for Industry Program.

The Philippines are currently classified as being in the learning phase; nevertheless, there are many important obstacles to implement and develop NIS. Firstly, there is a need to enhance cooperation and spill-over among various stakeholders, such as industry, government and academia, including specificity of sectors and companies involved. Secondly, intellectual property rights (IPR) could be better protected and effective, striking a balance between incentives and restrictions dedicated to FDI. Thirdly, regular cooperation between universities and the private sector is necessary to develop products and to commercialise R&D results. Fourth, both public and private R&D expenditure might be higher, including introduction of effective financing schemes dedicated to start-ups under internationally recognised standards.

2.2.4. Singapore

Singapore has experienced dynamic economic growth and technological development since 1965 due to inward FDI attracted by a business-friendly macroeconomic environment, low taxes and a highly-skilled labour force. In 2016, the Research, Innovation and Enterprise 2020 Plan was launched to increase the innovation capacities of the private sector. Financial resources are distributed within the white space under the supervision of the National Research Foundation.

An important component of Singapore’s innovation policy is the development of knowledge-based industrial clustering [17]. The timing of government intervention depends on the maturity and specificity of a sector. The Economic Development Board (EDB) was established to serve as a one-stop shop to attract FDI and talents under the slogan of Singapore’s innovation strategy: ‘Home for Business, Home for Talent, Home for Innovation’. The geographical proximity of rapidly growing markets, such as China and India, has made Singapore a regional hub for many Western multinational corporations (MNCs) willing to tap into the economic dynamism in this part of the world.

It is critical for Singapore to maintain a competitive and consistent institutional regulatory framework for NIS, and to keep all relevant stakeholders, including the private sector, actively involved. As concluded by Ambashi et al. [11], Singapore is challenged nowadays by its transition from being a technology adopter to a technology innovator through the development of a technological entrepreneurial community. It seems then that knowledge-based industrial clustering is the key.

2.2.5. Thailand

Thailand experienced dynamic economic growth from the 1960s to the mid-1990s due to its successful transition from an agrarian to a manufacturing economy by attracting inward FDI. However, industrialisation with inadequate development of domestic technological capacities, accompanied by rising labour shortages and cost pressure, has resulted in a middle-income trap. This, in turn, has resulted in a growing emphasis on innovation to increase productivity and development through industrial upgrading instead of the diversification of export markets and sectors.

In institutional terms, Thailand’s innovation policy is fragmented and ineffective, including the functioning of NSTI Policy Committee and the National Research Council. Next to tax incentives, under 12th National Economic and Social Development Plan, the government assumes an increase in the R&D expenditures up to 2% of GDP with private sector shares up to 70% by 2021. In order to increase R&D personnel, the Thai government has established a set of scholarship schemes serviced by the Ministry of Science and Technology (MOST), as well as selected government agencies, such as the Thailand Research Fund, the Office of the Higher Education Commission, and the Institute for the Promotion of Teaching Science and Technology.

Thailand, is currently categorised as being in the learning phase. As such, Thailand needs to increase the level of public investment in R&D and to make the system more demand-driven, to implement transparent systems of evaluation and monitoring of public R&D expenditure, to establish
an institutional core/coordinator of innovation policy and to promote human resources development, considering, among others, unfavourable demographic trends.

### 2.2.6. Vietnam

Vietnam has evolved gradually from centrally planned to socialist market economy, experiencing high rates of growth in the 1990s and 2000s. The innovation-oriented Đổi mới policy (Pillars of the policy were as follows: development of institutional frameworks of the market economy; macroeconomic stability; and economic integration at regional and global level) since the mid-1980s has addressed both micro and macro level innovation. Nevertheless, Đổi mới has proved insufficient to maintain high quality growth and labour productivity in the long term.

The institutional frameworks underpinning Vietnam’s innovation policy was strengthened by the establishment of, among others, the National Council for Science and Technology Policy, the State Agency for Technology Innovation and the National Foundation for Science and Technology Development. In 2005 and 2009, IPR regulations were updated to meet the standards of international innovation system. STI development and innovation were prioritised in Socio-economic Development Strategy 2011–2020 and the Socio-economic Development Plan 2016–2020.

In conclusion, there are a number of important obstacles needing to be overcome before making the transition from the learning to the catching-up phase in terms of innovation policy. Firstly, the institutional environment of innovation policy is inconsistent, with different agencies and institutions involved in the design and implementation of STI policy, including IPR. Secondly, systems of financing R&D are ineffective, primarily being sponsored by public expenditure. Thirdly, R&D personnel are limited and lack higher skills due to the poor performance of the tertiary education system in Vietnam. Fourthly, cooperation between industry and academia, including technology transfers and spill-overs, is limited and weak, mainly because of limited resources. While addressing these obstacles, the Vietnamese central government should put emphasis on enhancing the private sector’s involvement in innovation.

As previously observed, three less developed AMS (i.e., Cambodia, Lao PDR and Myanmar) lack NIS, prioritising different economic and social development objectives, such as poverty reduction, as well as the modernisation of agriculture and infrastructure. In both the Lao PDR and Myanmar, the Ministry of Science and Technology (MOST) is responsible for STI policies and STI legislation, which is expected to provide the framework for the future NIS. Importantly, less developed AMS cooperate under such programs as Science and Technology Research Partnership for Sustainable Development (SATREPS) and e-ASIA Joint Research Program (e-ASIA JRP) with institutions from Japan and South Korea, including Japan International Cooperation Agency (JICA), Japan’s Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan Science and Technology Agency (JST) and Korea International Cooperation Agency (KOICA) [18]. On the other hand, resource-abundant Brunei Darussalam, which has not been classified in terms of the innovation policy typology, is currently involved in two Japanese programs (e.g., ASEAN exchanges of the Institute of Advanced Energy at Kyoto University and solar energy generation experimental facility of Mitsubishi Corporation). Considering rising R&D expenditure and the construction plans for the Bio-Innovation Corridor in the National Development Plan, Brunei Darussalam seems to be preparing itself for the post-oil and -gas era in the economic development.

### 2.3. Studies on Innovation Efficiency for ASEAN

Data envelopment analysis (DEA) studies of R&D spending efficiency are an increasingly popular topic in the scientific literature. The choice of variables and models leads to different conclusions and recommendations. Nevertheless, empirical studies on R&D spending efficiency are still limited and need to be supplemented, especially with respect to the developing countries of ASEAN economies. Table 2 presents a cross-country analysis of DEA innovation studies, which include some of the ASEAN and Asia-Pacific countries.
Table 2. Cross-country innovation studies for Association of Southeast Asian Nations (ASEAN) and ASIA-PACIFIC countries using DEA methodology.

| Input and Output Variables | DEA Model Used | List of Countries in the Studied Sample | Efficient Countries |
|----------------------------|----------------|----------------------------------------|--------------------|
| **Input variables**: imports of goods and commercial services, gross domestic expenditure on research, degree of private business involvement in R&D, Employment in R&D, Total educational expenditures. Output variables: External patents by resident, Patents by a country’s residents, National productivity | CRS, input-oriented DEA model | 46 countries, 14 from ASEAN and ASIA-PACIFIC: Australia, China, Hong Kong, India, Indonesia, Israel, Japan, Malaysia, New Zealand, Philippines, Singapore, South Korea, Taiwan, Thailand | Fully efficient (in all three models and all two periods of study): Japan, Taiwan Partially efficient (at least in one model or in one year): Hong Kong |
| **Input variables**: BERD, GERD, GOVERD, HERD Researchers. Output variables: Weighted Patents, Unweighted Patents | VRS, output oriented DEA model | 28 countries, 3 from ASEAN and ASIA-PACIFIC: China, Japan, South Korea. | Among Asia countries Japan was the most efficient, then South Korea. China was characterized by a very low rate of knowledge production, suggesting that they are still in the phase of imitating and replicating existing technologies. |
| **Input variables**: number of scientists in R&D, expenditure on education and R&D expenditures. Output variable: patent counts, royalty incomes and license fees, high-technology export and manufacturing exports. | Virtual DEA based innovation index on the basis of VRS, output oriented DEA model | 42 countries, 10 from ASEAN and ASIA-PACIFIC: Australia, China, Hong Kong, Iran, Israel, Japan, Kyrgyzstan, New Zealand, South Korea, Thailand. | Study results are very unclear and hard to understand. |
| **Input variables**: General Expenditures on R&D (GERD), Total R&D personnel. Output variables: WIPO patents granted, Scientific and technical journal articles, High-technology and ICT services exports. | CRS, output oriented DEA model | 22 countries, 4 from ASEAN and ASIA-PACIFIC: China, India, Japan, South Korea. | India and China have relatively high efficiency score and good ranking |
Table 2. Cont.

| Input and Output Variables | DEA Model Used | List of Countries in the Studied Sample | Efficient Countries |
|----------------------------|----------------|----------------------------------------|---------------------|
| Input variables: R&D expenditure stocks (million US dollars in year 2000); Total R&D manpower (full-time equivalent units). | CRS, output oriented DEA model | 24 countries, 3 from ASEAN and ASIA-PACIFIC: Japan, Singapore, South Korea. | South Korea was efficient in some years of period of study. |
| Output variables: patents applied for in the EPO and USPTO, Scientific journal articles, Royalty and licensing fees. (million US dollars in year 2000). | | | |
| Input variables: prior accumulated knowledge stock participating in downstream knowledge commercialization with incremental knowledge; consumed full-time equivalent labor for non-R&D activities; number of full-time equivalent scientists and engineers; incremental R&D expenditure funding innovation activities; prior accumulated knowledge stock breeding upstream knowledge production. | VRS and CRS, output-oriented DEA model; Super-efficiency DEA model | 22 countries, 3 from ASEAN and ASIA-PACIFIC: Japan, Singapore, South Korea. | Japan was efficient in two models. |
| Output variables: Number of patents granted by United States Patent and Trademark Office; international scientific papers; added value of industries; export of new products in high-tech industries. | | | |

Source: Authors’ own study on literature review.
Nasierowski and Arcelus [19] studied the NIS efficiency of 46 countries, reporting differences in efficiency and the components of NIS policies (i.e., scale and congestion). This assessment of the impact of R&D on a country’s productivity led the authors to conclude that most of the economies subjected to analysis were operating under a variable return to scale (VRS) model. Authors remarked at the dichotomy among countries in terms of their commitment to technological efforts; while some overinvested in certain technological domains, negatively impacting their overall efficiency, others underinvested in R&D, recording reduced returns. The latter empirical result seemed to confirm many of the finding present in the literature.

Cullmann, Schmidt-Ehmcke and Zloczysti [20] investigated the relative efficiency of knowledge production in OECD countries based on intertemporal frontier estimation. The authors addressed the impact of the regulatory environment using the single bootstrap procedure described by Simar and Wilson (2007). The authors confirmed the hypothesis that limited competition, encouraged by entry barriers in regulatory dimensions, negatively impacts R&D efficiency due to the ineffective allocation of resources and eroding incentives to innovate because of the lack of pressure imposed on existing companies by new market entrants, with special regard to entrepreneurs.

Abbasi, Hajihoseini and Haukka [21] proposed a DEA-based virtual index consisting of three input and four output indicators to measure the relative innovativeness of economies, further adopting a multi-stage virtual benchmarking process to propose best and rational benchmarks for NISs assessed as inefficient. The authors found the Tobit and ordinary least squares (OLS) regression model as a useful instrument for providing an empirical explanation of changes in the performances of individual economies with inefficient NIS. It was concluded that there is a potential to improve the efficiency of individual economies without additional inputs to NISs. Moreover, a rapid increase in the contribution of these countries to R&D would not improve their performance. Abbasi et al. [11] stress that innovation may be found as business-driven rather than technology-driven, taking into account that both the increased trade in goods and services in terms of shares in GDP and women’s participation in industry might improve the efficiency of NIS.

Cai [22] adopted an NIS approach and new growth theory to calculate the efficiency of 22 economies, including BRICS and the G7. The author found that the first of these groups were highly diversified in respect to NIS performance, with China and India ranking relatively high. Key determinants of NIS efficiency include ICT infrastructure, education system, market environment, economies of scale, governance, natural resources, external links and enterprise R&D. The latter was identified as the most important in the context of the efficiency of NIS. On the other hand, Cai [22] also appreciated the impacts of ICT infrastructure, economies of scale and openness as critical for the diffusion of technologies and knowledge, and thus the efficiency of NIS. The BRICS economies were characterised as natural resources-dependent, with low quality of governance, threaten by the middle-income trap. Therefore, a set of reforms was recommended to enhance transformation into the innovation-driven growth pattern.

Chen et al. [23] investigated the efficiency of R&D using a panel dataset of 24 countries with selected output-oriented indices. An empirical study indicated that economies differed in terms of journal publications, whereas the results of R&D efficiency in patents and royalties proved to be quite similar. Chen et al. [23] noted considerably positive impacts of an innovation environment’s components, such as R&D intensity, protection of IPRs, as well as knowledge stock and human capital accumulation on R&D efficiency indices. Furthermore, enterprise R&D, both funded by the private business sector and foreign capital, proved to be an important trigger of improvement on the R&D efficiency index in respect to licensing fees, royalties and patents. On the other hand, the journal-oriented R&D efficiency index was positively influenced by the R&D intensity of higher education institutions.

Guan and Chen [24] proposed a relational network DEA model to measure the efficiency of NIS through the decomposition of the innovation process into a network with a two-stage innovation production framework, consisting of an upstream knowledge production process (KPP) and a
downstream knowledge commercialisation process (KCP). Furthermore, the authors studied the effects of a policy-based institutional environment on innovation efficiency using a second step, partial least squares regression, to address such problems as multicollinearity, small datasets and a limited number of distribution assumptions. In the case of most OECD countries studied in the paper, a non-coordinated relationship between upstream R&D efficiency and downstream commercialisation efficiency was identified, resulting in significant rank differences. It was found that the overall innovation efficiency of NIS was considerably impacted by downstream commercialisation efficiency performance, thus this component of the innovation production network should be addressed by the future innovation-oriented policies in OECD economies. The empirical results of partial least squares regression analysis led to the formulation of a set of recommendations in terms of public policy interventions by the government aimed at improvements in NIS performance. Specifically, in the case of countries assessed as innovation leaders in terms of CRS efficiency measures (i.e., with relatively higher KPP and KCP efficiency performance), an improvement in innovation output may be difficult to achieve without increasing innovation input, while in the case of countries categorised as innovation followers (i.e., those with relatively lower KPP and KCP efficiency performance), both components require improvement. Without appropriate policies in place, an increase in innovation input will not improve innovation outputs or outcomes in these second group of countries. As a result, improved efficiency of the country may result in higher output and outcomes without additional innovation inputs. On the other hand, countries with diversified KPP and KCP efficiencies are recommended to introduce more stage-specific innovation policies; for instance, in the case of lower KPP and higher KCP efficiency performance, it might be useful to strengthen the protection of IPRs and to finance schemes for R&D projects, while countries with higher KPP and lower KCP should enhance market-driven innovation.

While the study of R&D spending efficiency is not in terms of economic analysis, empirical evidence still a fundamental requirement. This paper makes a number of contributions to the existing R&D efficiency literature. Firstly, this article provides a study of R&D efficiency in the context of ASEAN economies. We found no prior R&D efficiency studies published in the ASEAN or Asia Pacific context; as such, this paper fills a gap in the literature. The studies presented in Table 2 took into account only some of the ASEAN and Asia Pacific countries together with other economies from around the world. An analysis of countries from the same region will allow for the identification of regional innovative frontiers. Secondly, this analysis focuses on a long period of 17 years, from 2000 to 2016. Other studies usually took into account significantly shorter periods. Such a long period will allow for the identification of efficiency trends in the analysed economies.

3. Methodology

The main research method used in this study is the DEA methodology, which is a nonparametric method that relies on linear programming benchmarking to assess the relative efficiency of decision-making units (DMUs) with multiple outputs and multiple inputs. This methodology was introduced by Farrell [25] and developed by Charnes et al. [26]. The maximum performance value for each DMU relative to all DMUs in the studied group can be calculated with DEA. DEA constructs the efficiency production frontier over the data points which serves as a benchmark for efficiency measures. DEA is used to determine which DMUs operate as efficiency frontiers and which DMUs do not; moreover, this approach allows for the benchmarking of distance from the frontier at the nearest point [27]. Efficient DMUs are not necessarily production frontiers, but rather best-practice frontiers [28]. It is important to note that DEA measures relative technical efficiency, because DEA measures are based on a reference group of units that are compared with each other and engaged in the same production process.

DEA can use input or output oriented models. An input-oriented model seeks to identify technical efficiency as a proportional reduction in input usage with outputs remaining unchanged. Efficiency in an output-oriented model is represented by a proportional increase in outputs, while the proportion of inputs remains unchanged [29]. DEA models can use constant return to scale (CRS) or variable
return to scale (VRS). However, the interpretation of VRS is much more complex than CRS, with VRS used only to control increasing or decreasing returns [30]. Slack-based context-dependent DEA is an important extension of DEA methodology, which illustrate target of improvement for the inefficient DMUs. Step-by-step improvement is a useful way to improve performance, and the benchmark target for each step is provided based on the evaluation context at each level of efficient frontier. The slack-based context-dependent DEA allows for a more complete evaluation of the inefficiency of a DMU’s performance [31].

Relative efficiency is calculated as the ratio of the weighted sum of outputs to the weighted sum of inputs [32]. The principle of the CRS model is maximisation of this ratio, shown below in Equations (1)–(3) [26]:

\[
\text{Max } \theta_0 = \frac{\sum_{s=1}^{S} u_r y_{rj}}{\sum_{m=1}^{M} v_m x_{mj}}, \quad (1)
\]

subject to:

\[
\frac{\sum_{i=1}^{S} u_r y_{rj}}{\sum_{m=1}^{M} v_m x_{mj}} \leq 1, \quad (2)
\]

where:

\(u_r, v_m \geq 0; s = 1, \ldots, S; m = 1, \ldots, M\)

\(y_{rj}\)—output

\(x_{mj}\)—input

VRS calculation requires an additional constraint equation [33]:

\[
\sum_{i=1}^{n} \lambda j = 1 \quad (3)
\]

where \(\theta\) is the efficiency score calculated for each DMU, \(\lambda\) is the corresponding solution vector for the optimisation and \(n\) is the number of DMUs.

The DEA methodology has many advantages. There is no need to define the function form of the relationship between input and outputs, and it can be used for the analysis of processes where the relationship between variables is of an unknown nature [34]. Secondly, DEA allows for the analysis of multiple inputs and outputs at the same time. Also, there is no need for a priori information regarding which inputs and outputs are the most important in the efficiency assessment [35]. Moreover, the causes of inefficiency can be analysed and quantified for each DMU [36].

Nevertheless, the DEA methodology also has some limitations. DEA does not take into account qualitative variables, which may result in some important factors being omitted from the analysis. Some authors are critical of DEA as overestimating efficiency, underlining that DEA provides information more about dominant DMUs [34]. Zhang and Bartels [37] also described a negative correlation between efficiency and the number of DMUs, with an increase in the number of DMUs reducing technical efficiency. Therefore, DEA necessitates the careful interpretation of results.

These issues also present certain limitations with respect to the current research. Firstly the variables we focused on were chosen based on available international statistics. The selected group of inputs and outputs have a crucial impact on the results of the efficiency measurement. Secondly, we initially selected only ASEAN economies for analysis, which gave us a smaller number of DMUs. To increase number of DMUs, additional Asia Pacific economies were selected for analysis. The analysis would be more complex if this study had analysed additional indicators, such as scientific and technical journal articles, human capital in innovation, etc. Nevertheless, expanding the number of indicators would also reduce the discriminatory power of the DEA. Lastly, it is necessary to observe that in the
analysed case, DEA is only an assessment of relative efficiency for the selected group of 15 countries. Expanding the research group may render the DMUs analysis ineffective.

4. Data

Calculations for the purposes of examination of the relationship between innovation expenditure and innovation results were performed in a Microsoft Excel spreadsheet and DEA Frontier software. From the ASEAN group, only seven (i.e., Indonesia, Cambodia, Malaysia, Philippines, Singapore, Thailand, and Vietnam) out of 10 countries were analysed due to a lack of available statistics. To obtain comparable peer groups and an appropriate number of DMUs, the study was extended to an additional eight countries from the Asia Pacific region (i.e., Australia, China, Hong Kong, India, Japan, Korea, Sri Lanka, New Zealand). The research period is inclusive of 17 periods from 2000 to 2016. The research methodology was DEA.

Diagnostic variables were selected based on available data from the World Bank. Input indicators included annual public and private spending on innovation (as % of GDP), represented by RDE. The four output indicators chosen for analysis were as follows: (a) high-technology exports as a percentage of manufactured exports, (b) patent applications (PA) according to WIPO by priority year for million inhabitants, (c) TA for million inhabitants, and (d) ICT exports as a percentage of manufactured exports. We took into consideration a number of important principle with respect to the selection of variables [38].

\[ n \geq 3 \times (s + m) \]  

where

\( s \)—number of inputs  
\( m \)—number of outputs  
\( n \)—numbers of DMUs

Given the limited data with respect to ASEAN countries, we added data from several Asia Pacific economies so as to produce more reasonable results via the DEA methodology. Based on the aforementioned formula, at least 15 DMUs should be analysed. It is important to take this rule into account otherwise the results may be erroneous, with some countries appearing more efficient when in reality they are not. In some cases, if the number of DMUs cannot be increased due to a lack of data, DEA window analysis can be applied. Another important rule in DEA is the coincidence between the inputs and outputs. Correlation coefficients between inputs and outputs should be verified. Output variables with a positive correlation to input variables can remain in the model. Pearson’s linear correlation coefficient was also calculated [39]:

\[ r_{ij} = \frac{\text{cov} (X_i, Y_j)}{s_is_j} \]  

where:

\( \text{cov} (X_i, Y_j) \)—covariance between \( i \)-variable and \( j \)-variable  
\( s_i \)—standard deviation of variable \( X_i \)  
\( s_j \)—standard deviation of variable \( X_j \).

All selected variables fulfilled this assumption for all years from 2000 to 2016.

Table 3 presents the final set of analysed variables with their descriptions. Table 4 shows the input and output data for ASEAN and Asia Pacific countries in 2016. Due to the lack of available data, some indicators are marked ‘*’, indicating that the values had been taken from the preceding or the following period, or their average.
Table 3. Indicators and sources.

| Variable | Full Indicator Name | Units | Source |
|----------|---------------------|-------|--------|
| RDE      | The annual public and private spending on innovation | (as % GDP) | World Bank |
| PA       | Number of patent applications, total * | (Per million inhabitants) | World Bank |
| TA       | Trademark applications, total * | (Per million inhabitants) | World Bank |
| HTE      | Exports of high-tech products | (% of exports) | World Bank |
| ICT      | Exports of ICT products | (% of exports) | World Bank |

Note: WIPO. Source: [40]. * lack of available data, some indicators are marked.

Table 4. Diagnostic data of inputs and outputs–ASEAN and ASIA-PACIFIC countries in 2016.

| 2016 | Country/Indicators (2016) | RDE | HTE | TA | PA | ICT |
|------|---------------------------|-----|-----|----|----|-----|
| 1    | AUS                       | 1.58| 14.78| 2986.31 | 1172.78 | 1.31 |
| 2    | CHN                       | 2.11| 25.24| 1526.41 | 970.87 | 26.50 |
| 3    | HKG                       | 0.76| 12.12| 4931.58 | 1920.78 | 49.99 |
| 4    | IDN                       | 0.07| 5.79 | 241.04 | 32.70 | 3.37 |
| 5    | IND                       | 0.63| 7.13 | 223.76 | 172.56 | 0.95 |
| 6    | JPN                       | 3.14| 16.22| 1283.39 | 2507.05 | 8.31 |
| 7    | KHM                       | 0.12| 0.43 | 104.43 | 4.12 | 1.90 |
| 8    | KOR                       | 4.23| 26.58| 3548.96 | 4075.07 | 22.27 |
| 9    | LKA                       | 0.10| 0.84 | 510.68 | 27.02 | 0.39 |
| 10   | MYS                       | 1.30| 42.97| 1253.94 | 232.02 | 30.53 |
| 11   | NZL                       | 1.23| 10.14| 4824.00 | 1360.69 | 1.03 |
| 12   | PHL                       | 0.14| 55.10| 317.23 | 33.09 | 43.21 |
| 13   | SGP                       | 2.20| 48.85| 4055.44 | 1958.17 | 33.64 |
| 14   | THA                       | 0.63| 21.51| 749.50 | 113.56 | 15.79 |
| 15   | VNM                       | 0.37| 26.93| 517.24 | 55.28 | 31.24 |
| 16   | Average for ASEAN countries | 0.69| 28.80| 1034.12 | 346.99 | 22.81 |
| 17   | Average for ASIA-PACIFIC countries | 1.24| 20.98| 1804.93 | 975.72 | 18.03 |

Note: AUS—Australia, CHN—China, HKG—Hong Kong, IDN—Indonesia, IND—India, JPN—Japan, KHM—Cambodia, KOR—Korea, Rep., LKA—Sri Lanka, MYS—Malaysia, NZL—New Zealand, PHL—Philippines, SGP—Singapore, THA—Thailand, VNM—Vietnam. Source: Authors’ own study based on [40].

5. Empirical Results and Discussion

The authors have chosen the input-oriented model to verify whether a DMU under evaluation can reduce its inputs while keeping the outputs at their current levels. The authors used the CRS and VRS methods. CRS reflects the fact that outputs will change by the same proportion as inputs are changed. In contrast, VRS reflects the fact that production technology can exhibit increasing, constant
and decreasing returns to scale. The results of CRS are presented in Table 5, while the VRS results are shown in Table 6.

Table 5. The efficiency of spending on innovation in 2016 (constant return to scale (CRS)).

| DMU No. | DMU Name | Input-Oriented CRS Efficiency | Sum of λ | RTS | Optimal Lambdas (λ) with Benchmarks | BDMU | λ | BDMU |
|---------|----------|--------------------------------|----------|-----|------------------------------------|------|---|------|
| 1       | AUS      | 0.30563                         | 0.743    | Increasing | 0.608 | dmu3 | 0.134 | dmu12 |
| 2       | CHN      | 0.20323                         | 0.848    | Increasing | 0.499 | dmu3 | 0.348 | dmu12 |
| 3       | HKG      | 1.00000                         | 1.000    | Constant  | 1.000 | dmu3 |       |      |
| 4       | IND      | 0.67610                         | 0.138    | Increasing | 0.043 | dmu3 | 0.096 | dmu12 |
| 5       | JPN      | 0.31664                         | 1.312    | Decreasing | 1.305 | dmu3 | 0.007 | dmu12 |
| 6       | KHM      | 0.15226                         | 0.041    | Increasing | 0.020 | dmu3 | 0.021 | dmu12 |
| 7       | KOR      | 0.38256                         | 2.137    | Decreasing | 2.121 | dmu3 | 0.016 | dmu12 |
| 8       | LKA      | 0.78184                         | 0.104    | Increasing | 0.104 | dmu3 |       |      |
| 9       | MYS      | 0.19970                         | 0.941    | Increasing | 0.207 | dmu3 | 0.734 | dmu12 |
| 10      | NZL      | 0.60543                         | 0.978    | Increasing | 0.978 | dmu3 |       |      |
| 11      | PHL      | 1.00000                         | 1.000    | Constant  | 1.000 | dmu3 |       |      |
| 12      | SGP      | 0.39107                         | 1.673    | Decreasing | 1.008 | dmu3 | 0.665 | dmu12 |
| 13      | THA      | 0.23610                         | 0.491    | Increasing | 0.129 | dmu3 | 0.362 | dmu12 |
| 14      | VNM      | 0.36884                         | 0.713    | Increasing | 0.063 | dmu3 | 0.650 | dmu12 |

Source: Authors’ calculations in DEAFrontier.

Table 6. The efficiency of spending on innovation in 2016 (VRS).

| DMU No. | DMU Name | Input-Oriented VRS Efficiency | λ | DMU | λ | BDMU | λ | BDMU |
|---------|----------|--------------------------------|---|-----|---|------|---|------|
| 1       | AUS      | 0.31339                         | 0.604 | HKG | 0.291 | IDN | 0.105 | PHL |
| 2       | CHN      | 0.20667                         | 0.497 | HKG | 0.173 | IDN | 0.331 | PHL |
| 3       | HKG      | 1.00000                         | 1.000 | HKG |       |     |      |      |
| 4       | IND      | 1.00000                         | 1.000 | IDN |       |     |      |      |
| 5       | JPN      | 0.19176                         | 0.074 | HKG | 0.908 | IDN | 0.018 | PHL |
| 6       | KHM      | 0.54461                         | 0.723 | HKG | 0.272 | KOR | 0.004 | SGP |
| 7       | KOR      | 1.00000                         | 1.000 | KOR |       |     |      |      |
| 8       | LKA      | 1.00000                         | 1.000 | LKA |       |     |      |      |
| 9       | MYS      | 0.20083                         | 0.200 | HKG | 0.065 | LKA | 0.735 | PHL |
| 10      | NZL      | 0.60586                         | 0.976 | HKG | 0.024 | LKA |       |      |
| 11      | PHL      | 1.00000                         | 1.000 | PHL |       |     |      |      |
| 12      | SGP      | 1.00000                         | 1.000 | SGP |       |     |      |      |
| 13      | THA      | 0.25647                         | 0.070 | HKG | 0.564 | LKA | 0.366 | PHL |
| 14      | VNM      | 0.39229                         | 0.048 | HKG | 0.309 | IDN | 0.643 | PHL |

Source: Authors’ calculations in DEAFrontier.

Among Asia-Pacific counties, only two were found to be efficient in 2016 under the CRS assumption for the overall process: Hong-Kong and the Philippines. The Philippines was found to be the only an
efficiency frontier among ASEAN countries. The remaining countries scored between 0 and 1, and according to DEA methodology can be identified as inefficient. These countries can improve their efficiency or reduce their inefficiencies proportionately by reducing their inputs. In 2016, India obtained the worst result (0.131); while among ASEAN countries, we found that Cambodia, scored only 0.152. Both economies could improve their efficiency by reducing R&D expenditure up to 86.90% (1–0.131) and 84.80% (1–0.152), respectively. The DEA methodology also allow us to identify benchmarks (BDMU), which are effective units. Ineffective units should follow the innovation polices of benchmark DMUs or develop organisational solutions in order to recognise the best practices and their possible adaptation to improve their expenditure transformation processes. For example, the benchmark for New Zealand is Hong-Kong, while the benchmark for Thailand is Hong-Kong and the Philippines. Thailand should attempt to become more like the Philippines than as Hong-Kong, as suggested by higher lambda weight, respectively $\lambda = 0.362$, $\lambda = 0.129$. For overall process in 2016, two countries (i.e., Hong-Kong and the Philippines) are scale efficient, and have optimal returns-to-scale. This can be seen in Table 3 in the RTS column. In addition, 10 countries (i.e., Australia, China, Indonesia, Cambodia, Sri Lanka, Malaysia, New Zealand, Thailand and Vietnam) have an increasing returns-to-scale, while three countries (i.e., Japan, Korea and Singapore) have a decreasing returns-to-scale.

Under VRS, we make the assumption that there are six efficient countries: Hong-Kong, Indonesia, Korea, Sri Lanka, Philippines and Singapore. From the ASEAN region, the efficiency frontiers include Singapore, the Philippines and Indonesia. Similar to the CRS model, India and China were the least efficient (0.19176 and 0.20667, respectively). It is noteworthy that more countries are efficient under the VRS assumption, as all relatively CRS efficient DMUs are scale efficient too.

The DEA methodology allows us to investigate potential improvements, which is presented in Table 7 for all indicators in 2016 for both CRS and VRS methodologies. Less efficient countries might become more efficient by implementing proposed improvements. In terms of inputs, potential improvement refers to the percentage difference between the target amount and the actual amount of input and output for each country. In order to improve efficiency, a country can increase its outputs or decrease its inputs. It is noteworthy to mention that improvement suggestions obtained by countries for CRS and VRS models are not the same. In CRS, two out of 15 countries (i.e., Hong Kong and the Philippines) are efficient. Based on potential improvements results from DEA model can be concluded that Australia, China, Indonesia Japan, Korea and Singapore in order to improve the efficiency index should concentrate on increasing their number of trademark applications. In order to become more efficient Australia, China, Indonesia, India, Japan, Korea, Sri Lanka, Malaysia, New Zealand, Singapore and Thailand need to focus on increasing their ICT exports. Similar recommendations can be deduced from the second model (VRS). Also, inefficient countries can become efficiency frontiers by decreasing their R&D expenditure; this is especially true when these expenditures are very high and the country is not able to use all of them due to, for example, a lack of technology. However, it is worth paying attention to the pressure of politics.

To expand the analysis, the authors assessed the efficiency of spending on innovation for an additional 16 years (2000–2016), for which a similar procedure was carried out. The final results are presented in Tables 8–10.

The analysis calculated efficiency indicators for several ASEAN and Asia Pacific economies. The research input-oriented model was chosen using CRS and VRS methodology for analysis. In addition, the average efficiency indicator was calculated for a change in indicator between 2000 and 2016. The average efficiency score is the arithmetic average of efficiency scores across 17 years. Table 8 shows the final efficiency index for CRS and Table 9 for VRS.
Table 7. Potential improvement in outputs at the current level of inputs and inputs at the current level of outputs for ASEAN and ASIA-PACIFIC countries in 2016.

| Input-Oriented/CRS Model Slacks | Input Slacks | Output Slacks | CRS Model Target | Efficient Input Target | Efficient Output Target | Potential Improvement for Inputs or Outputs (%) | Potential Improvement for Inputs or Outputs (Values) |
|----------------------------------|--------------|---------------|-------------------|------------------------|-------------------------|-----------------------------------------------|-----------------------------------------------|
| DMU No. | DMU Name | RDE | HTE | TA | PA | ICT | DMU No. | DMU Name | RDE | HTE | TA | PA | ICT | RDE | HTE | TA | PA | ICT | RDE | HTE | TA | PA | ICT |
|--------|----------|-----|-----|----|----|-----|--------|----------|-----|-----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1      | AUS      | 0.00| 0.00| 56.02| 0.00| 34.91| 1      | AUS      | 0.48| 14.78| 3042.33| 1172.78| 36.22| -69.44%| 0.00%| 1.88%| 0.00%| 2670.43%| -1.09| 0.00| 56.02| 0.00| 34.91|
| 2      | CHN      | 0.00| 0.00| 1047.14| 0.00| 13.52| 2      | CHN      | 0.43| 25.24| 2573.55| 970.87| 40.01| -79.68%| 0.00%| 68.60%| 0.00%| 51.01%| -1.68| 0.00| 1047.14| 0.00| 13.52|
| 3      | HKG      | 0.00| 0.00| 0.00 | 0.00| 0.00 | 3      | HKG      | 0.76| 12.12| 4931.58| 1920.78| 49.99 | 0.00%| 0.00%| 0.00%| 0.00%| 0.00% | 0.00| 0.00| 0.00 | 0.00| 0.00|
| 4      | IDN      | 0.00| 0.00| 52.53 | 2.90| 0.00 | 4      | IDN      | 0.05| 5.79 | 241.04 | 85.23 | 6.27 | -32.39%| 0.00%| 0.00%| 160.66%| 86.03% | -0.02| 0.00| 0.00 | 52.53| 2.90|
| 5      | IND      | 0.00| 0.00| 244.83| 0.00| 8.20 | 5      | IND      | 0.76| 12.12| 4931.58| 1920.78| 49.99 | 0.00%| 0.00%| 0.00%| 0.00%| 0.00% | 0.00| 0.00| 0.00 | 0.00| 0.00|
| 6      | JPN      | 0.00| 0.00| 5155.10| 0.00| 57.25 | 6      | JPN      | 0.99| 16.22| 6438.49| 2507.05| 65.56 | -68.34%| 0.00%| 401.68%| 0.00%| 688.61%| -2.15| 0.00| 5155.10| 0.00| 57.25|
| 7      | KHM      | 0.00| 0.00| 34.64 | 0.00| 0.00 | 7      | KHM      | 0.02| 1.40 | 104.43 | 38.76 | 1.90 | -84.77%| 224.68%| 0.00%| 839.97%| 0.00% | -0.10| 0.97| 0.00 | 34.64| 0.00|
| 8      | KOR      | 0.00| 0.00| 6917.40| 0.00| 84.46 | 8      | KOR      | 1.62| 26.58| 10466.36| 4075.07| 106.73 | -61.74%| 0.00%| 194.91%| 0.00%| 379.25%| -2.61| 0.00| 6917.40| 0.00| 84.46|
| 9      | LKA      | 0.00| 0.00| 171.88| 4.79 | 0.00 | 9      | LKA      | 0.08| 1.26 | 510.68 | 198.90 | 5.18  | -21.82%| 48.89% | 0.00%| 636.01%| 1222.70%| -0.02| 0.41| 0.00 | 171.88| 4.79|
| 10     | MYS      | 0.00| 0.00| 189.94| 11.55| 0.00 | 10     | MYS      | 0.26| 42.97| 1253.94| 421.96 | 42.09 | -80.03%| 0.00%| 0.00%| 81.86% | 37.83% | -1.04| 0.00| 0.00 | 189.94| 11.55|
| 11     | NZL      | 0.00| 1.71| 518.19| 47.87 | 0.00 | 11     | NZL      | 0.74| 11.86| 4824.00| 1878.88| 48.90 | -39.46%| 16.88% | 0.00%| 4630.64%| 46.64% | -0.49| 1.71| 0.00 | 518.19| 47.87|
| 12     | PHL      | 0.00| 0.00| 0.00  | 0.00| 0.00 | 12     | PHL      | 0.14| 55.10| 317.23 | 33.09 | 43.21 | 0.00% | 0.00% | 0.00%| 0.00%| 0.00% | 0.00| 0.00| 0.00 | 0.00| 0.00|
| 13     | SGP      | 0.00| 0.00| 1126.54| 0.00| 45.49 | 13     | SGP      | 0.86| 48.85| 5181.98| 1958.17| 79.12 | -60.89%| 0.00%| 27.78% | 0.00%| 135.23%| -1.34| 0.00| 1126.54| 0.00| 45.49|
| 14     | THA      | 0.00| 0.00| 145.60| 6.30 | 0.00 | 14     | THA      | 0.15| 21.51| 749.50 | 259.16 | 22.08 | -76.39%| 0.00%| 128.22%| 39.88% | -0.48| 0.00| 0.00 | 145.60| 6.30|
| 15     | VNM      | 0.00| 9.65| 87.38 | 0.00| 0.00 | 15     | VNM      | 0.14| 36.58| 517.24| 142.66| 31.24 | -63.12%| 35.81% | 0.00%| 158.06%| 0.00% | -0.24| 9.65| 0.00 | 87.38| 0.00|
### Table 7. Cont.

| DMU No. | DMU Name | Input Slacks | Output Slacks | VRS Model Target | Efficient Input Target | Efficient Output Target | Potential Improvement for Inputs or Outputs (%) | Potential Improvement for Inputs or Outputs (Values) |
|---------|----------|--------------|---------------|------------------|------------------------|------------------------|-------------------------------------------------|--------------------------------------------------|
| 1       | AUS      | 0.00         | 0.00          | 94.91            | 0.00                   | 34.39                  | 0.49                                            | 14.78                                            |
|         |          | 0.00         | 0.00          | 3081.22          | 1172.78                | 35.70                  | -68.66%                                         | 3.18%                                           |
| 2       | CHN      | 0.00         | 0.00          | 1070.18          | 0.00                   | 13.21                  | 0.44                                            | 25.24                                            |
|         |          | 0.00         | 0.00          | 2596.59          | 970.87                 | 39.70                  | -79.33%                                         | 70.11%                                          |
| 3       | HKG      | 0.00         | 0.00          | 0.00             | 0.00                   | 0.00                   | 0.76                                            | 12.12                                            |
|         |          | 0.00         | 0.00          | 4931.58          | 1920.78                | 49.99                  | 0.00%                                           | 0.00%                                           |
| 4       | IDN      | 0.00         | 0.00          | 0.00             | 0.00                   | 0.00                   | 0.07                                            | 5.79                                            |
|         |          | 0.00         | 0.00          | 241.04           | 32.70                  | 3.37                   | 0.00%                                           | 0.00%                                           |
| 5       | IND      | 0.00         | 0.00          | 366.05           | 0.00                   | 6.58                   | 0.12                                            | 7.13                                            |
|         |          | 0.00         | 0.00          | 589.82           | 172.56                 | 7.53                   | -80.82%                                         | 165.59%                                         |
| 6       | JPN      | 0.00         | 0.00          | 3268.09          | 0.00                   | 34.06                  | 1.71                                            | 16.22                                            |
|         |          | 0.00         | 0.00          | 4551.49          | 2507.05                | 42.38                  | -45.54%                                         | 254.64%                                         |
| 7       | KHM      | 0.00         | 0.00          | 136.61           | 28.57                  | 1.47                   | 0.07                                            | 5.79                                            |
|         |          | 0.00         | 0.00          | 241.04           | 32.70                  | 3.37                   | -42.78%                                         | 1238.31%                                        |
| 8       | KOR      | 0.00         | 0.00          | 0.00             | 0.00                   | 0.00                   | 4.23                                            | 26.58                                            |
|         |          | 0.00         | 0.00          | 3548.96          | 4075.07                | 22.27                  | 0.00%                                           | 0.00%                                           |
| 9       | LKA      | 0.00         | 0.00          | 0.00             | 0.00                   | 0.00                   | 0.10                                            | 0.84                                            |
|         |          | 0.00         | 0.00          | 510.68           | 27.02                  | 0.39                   | 0.00%                                           | 0.00%                                           |
| 10      | MYS      | 0.00         | 0.00          | 178.75           | 11.26                  | 0.00                   | 0.26                                            | 42.97                                            |
|         |          | 0.00         | 0.00          | 1253.94          | 410.77                 | 41.79                  | -79.92%                                         | 0.00%                                           |
| 11      | NZL      | 0.00         | 1.70          | 514.01           | 47.75                  | 7.74                   | 0.75                                            | 11.85                                            |
|         |          | 0.00         | 0.00          | 4824.00          | 1874.70                | 48.79                  | -39.41%                                         | 16.78%                                          |
| 12      | PHL      | 0.00         | 0.00          | 0.00             | 0.00                   | 0.00                   | 0.14                                            | 55.10                                            |
|         |          | 0.00         | 0.00          | 317.23           | 33.09                  | 43.21                  | 0.00%                                           | 0.00%                                           |
| 13      | SGP      | 0.00         | 0.00          | 0.00             | 0.00                   | 0.00                   | 2.20                                            | 48.85                                            |
|         |          | 0.00         | 0.00          | 4055.44          | 1958.17                | 33.64                  | 0.00%                                           | 0.00%                                           |
| 14      | THA      | 0.00         | 0.00          | 48.35            | 3.77                   | 0.00                   | 0.16                                            | 21.51                                            |
|         |          | 0.00         | 0.00          | 749.50           | 161.91                 | 19.56                  | -74.35%                                         | 42.58%                                          |
| 15      | VNM      | 0.00         | 10.86         | 0.00             | 69.14                  | 0.00                   | 0.15                                            | 37.79                                            |
|         |          | 0.00         | 0.00          | 517.24           | 124.42                 | 31.24                  | -60.77%                                         | 40.33%                                          |

Source: Authors' calculations in DEA Frontier.
Table 8. The efficiency of spending on innovation for ASEAN and ASIA-PACIFIC in 2000–2016 (CRS).

| CRS Effectiveness Index | CRS 2000 | CRS 2001 | CRS 2002 | CRS 2003 | CRS 2004 | CRS 2005 | CRS 2006 | CRS 2007 | CRS 2008 | CRS 2009 | CRS 2010 | CRS 2011 | CRS 2012 | CRS 2013 | CRS 2014 | CRS 2015 | CRS 2016 | Avarage Change 2000–2016 | Rank |
|-------------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|-----------------------------|------|
| 3                       | HKG     | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000           | 0.000 | 1   |
| 12                      | PHL     | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000   | 1.000           | 0.000 | 1   |
| 4                       | IDN     | 0.689   | 0.798   | 0.747   | 0.845   | 1.000   | 0.917   | 1.000   | 0.769   | 0.789   | 0.792   | 0.732   | 0.717   | 0.734   | 0.712   | 0.569   | 0.564   | 0.676           | 0.768 | 3   |
| 11                      | NZL     | 0.625   | 0.833   | 0.869   | 1.000   | 0.862   | 0.919   | 0.939   | 0.888   | 0.707   | 0.653   | 0.576   | 0.516   | 0.540   | 0.522   | 0.614   | 0.523   | 0.605           | 0.717 | 4   |
| 14                      | THA     | 0.537   | 0.546   | 0.657   | 0.685   | 0.739   | 0.764   | 0.644   | 0.736   | 0.708   | 0.629   | 0.486   | 0.368   | 0.333   | 0.313   | 0.269   | 0.233   | 0.236           | 0.522 | 5   |
| 9                       | LKA     | 0.253   | 0.276   | 0.330   | 0.367   | 0.413   | 0.475   | 0.502   | 0.488   | 0.543   | 0.425   | 0.411   | 0.498   | 0.594   | 0.600   | 0.584   | 0.631   | 0.782           | 0.481 | 6   |
| 13                      | SGP     | 0.443   | 0.426   | 0.439   | 0.531   | 0.543   | 0.597   | 0.569   | 0.486   | 0.302   | 0.393   | 0.457   | 0.366   | 0.398   | 0.382   | 0.408   | 0.391   | 0.445           | −0.052 | 7   |
| 8                       | KOR     | 0.371   | 0.381   | 0.423   | 0.535   | 0.564   | 0.572   | 0.486   | 0.449   | 0.410   | 0.457   | 0.446   | 0.362   | 0.374   | 0.369   | 0.415   | 0.450   | 0.383           | 0.438 | 8   |
| 7                       | KHM     | 0.353   | 0.424   | 0.478   | 0.225   | 0.472   | 0.450   | 0.366   | 0.559   | 0.549   | 0.514   | 0.521   | 0.488   | 0.485   | 0.502   | 0.375   | 0.152   | 0.412           | −0.201 | 9   |
| 6                       | JPN     | 0.425   | 0.471   | 0.471   | 0.533   | 0.534   | 0.471   | 0.388   | 0.351   | 0.335   | 0.383   | 0.385   | 0.313   | 0.335   | 0.293   | 0.323   | 0.347   | 0.317           | 0.393 | −0.108 | 10 |
| 15                      | VNM     | 0.163   | 0.172   | 0.183   | 0.244   | 0.295   | 0.354   | 0.420   | 0.473   | 0.426   | 0.453   | 0.416   | 0.476   | 0.379   | 0.388   | 0.323   | 0.342   | 0.349           | 0.346 | 0.206 | 11 |
| 1                       | AUS     | 0.272   | 0.301   | 0.314   | 0.349   | 0.412   | 0.440   | 0.433   | 0.406   | 0.358   | 0.355   | 0.323   | 0.282   | 0.298   | 0.314   | 0.311   | 0.354   | 0.306           | 0.343 | 0.034 | 12 |
| 10                      | MYS     | 0.532   | 0.455   | 0.395   | 0.432   | 0.472   | 0.448   | 0.446   | 0.398   | 0.305   | 0.246   | 0.242   | 0.234   | 0.220   | 0.206   | 0.192   | 0.188   | 0.200           | 0.330 | −0.333 | 13 |
| 2                       | CHN     | 0.081   | 0.095   | 0.110   | 0.126   | 0.138   | 0.127   | 0.125   | 0.122   | 0.112   | 0.110   | 0.125   | 0.132   | 0.135   | 0.150   | 0.170   | 0.199   | 0.203           | 0.133 | 0.122 | 14 |
| 5                       | IND     | 0.033   | 0.043   | 0.046   | 0.053   | 0.061   | 0.068   | 0.072   | 0.079   | 0.078   | 0.091   | 0.102   | 0.094   | 0.106   | 0.113   | 0.134   | 0.151   | 0.131           | 0.085 | 0.098 | 15 |

Source: Authors’ calculations.
Table 9. The efficiency of spending on innovation ASEAN and ASIA-PACIFIC in 2000–2016 (VRS).

| VSR | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | Average | Change 2000–2016 | Rank |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|--------|------------------|------|
|     | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | VRS  | 2000–2016 |          |      |
| 3   | HKG  | 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 0.000   | 1      |      |
| 4   | IDN  | 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 0.000   | 1      |      |
| 12  | PHL  | 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 0.000   | 1      |      |
| 13  | SGP  | 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 0.000   | 1      |      |
| 8   | KHM  | 0.780| 0.726| 0.832| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 0.961   | 0.220  | 5     |
| 7   | NZL  | 1.000| 1.000| 1.000| 1.000| 1.000| 1.000| 0.897| 0.892| 0.857| 0.821| 0.843| 0.813| 0.773| 0.798| 0.746| 0.572| 0.572   | 0.888  | −0.108 | 6     |
| 11  | THA  | 1.000| 1.000| 1.000| 1.000| 1.000| 0.761| 0.707| 0.737| 0.734| 0.738| 0.652| 0.684| 0.531| 0.585| 0.583| 0.545| 0.780   | 0.000  | 0.293  | 8     |
| 9   | LKA  | 0.469| 0.455| 0.481| 0.543| 0.485| 0.573| 0.658| 0.755| 0.649| 0.636| 0.771| 0.864| 0.920| 1.000| 1.000| 0.696| 0.189   | 0.000  | 0.000  | 9     |
| 10  | MYS  | 1.000| 1.000| 1.000| 1.000| 1.000| 0.449| 0.446| 0.310| 0.247| 1.000| 0.278| 0.242| 0.264| 0.189| 0.201| 0.625| 0.000   | 0.000  | 0.000  | 10    |
| 14  | THA  | 0.564| 0.569| 0.690| 0.703| 0.752| 0.798| 0.663| 0.780| 0.755| 0.678| 0.519| 0.401| 0.366| 0.345| 0.305| 0.261| 0.256   | 0.553  | 0.216  | 11    |
| 15  | VNM  | 0.352| 0.349| 0.331| 0.382| 0.375| 0.449| 0.461| 0.565| 0.536| 0.567| 0.522| 0.561| 0.419| 0.396| 0.358| 0.376| 0.392   | 0.435  | 0.213  | 12    |
| 1   | AUS  | 0.274| 0.304| 0.318| 0.354| 0.412| 0.441| 0.433| 0.409| 0.360| 0.360| 0.334| 0.291| 0.307| 0.321| 0.317| 0.359| 0.313   | 0.348  | 0.135  | 13    |
| 5   | IND  | 0.090| 0.101| 0.104| 0.120| 0.128| 0.129| 0.133| 0.138| 0.130| 0.142| 0.153| 0.144| 0.157| 0.161| 0.183| 0.204| 0.192   | 0.142  | 0.048  | 14    |
| 2   | CHN  | 0.103| 0.107| 0.118| 0.130| 0.139| 0.131| 0.127| 0.124| 0.114| 0.113| 0.125| 0.135| 0.140| 0.153| 0.174| 0.202| 0.207   | 0.138  | 0.022  | 15    |

Source: Authors’ calculations.
Table 10. Efficiency ranking for ASEAN and ASIA-PACIFIC in 2000–2016.

| Country | Average CRS Effectiveness Index | Average VRS Effectiveness Index | Average Effectiveness Index | Rank |
|---------|---------------------------------|---------------------------------|-----------------------------|------|
| HKG     | 1.000                           | 1.000                           | 1.000                       | 1    |
| PHL     | 1.000                           | 1.000                           | 1.000                       | 2    |
| IDN     | 0.768                           | 1.000                           | 0.884                       | 3    |
| NZL     | 0.717                           | 0.819                           | 0.768                       | 4    |
| SGP     | 0.445                           | 1.000                           | 0.723                       | 5    |
| KOR     | 0.438                           | 0.961                           | 0.700                       | 6    |
| KHM     | 0.412                           | 0.858                           | 0.635                       | 7    |
| LKA     | 0.481                           | 0.696                           | 0.589                       | 8    |
| JPN     | 0.393                           | 0.780                           | 0.586                       | 9    |
| THA     | 0.522                           | 0.553                           | 0.538                       | 10   |
| MYS     | 0.330                           | 0.625                           | 0.478                       | 11   |
| VNM     | 0.346                           | 0.435                           | 0.390                       | 12   |
| AUS     | 0.343                           | 0.348                           | 0.345                       | 13   |
| CHN     | 0.133                           | 0.138                           | 0.135                       | 14   |
| IND     | 0.085                           | 0.142                           | 0.114                       | 15   |

Average for ASEAN countries: 0.579, 0.782, 0.680
Average for ASIA-PACIFIC countries: 0.494, 0.690, 0.592

Source: Authors’ calculations.

The results from Tables 8 and 9 were used to calculate final efficiency index and efficiency ranking presented in Table 10. It is necessary to highlight that presented results are only in the short-term view. Table 10 identifies Hong Kong and the Philippines as the most efficient countries, both being efficient for each year under both CRS and VRS. According to the VRS model, Indonesia (1.00) and Singapore (1.00) are efficiency frontiers; however, these countries scored worse results under the CRS model, thus explaining why these countries assume the third and fifth places in the ranking. Seven out of 15 analysed countries obtained scores above the average 0.592: Hong Kong, the Philippines, Indonesia, New Zealand, Singapore, Korea and Cambodia. Other countries obtained scores below the average efficiency index: Sri Lanka, Japan, Thailand, Malaysia, Vietnam, Australia, China, India. The worst efficiency index was obtained by China and India. At the beginning of the research period, China spent < 1%, although the value has since come to in excess of 2% since 2014. China’s average spending on R&D in 2016 was 1.52% of the country’s GDP. India, on the other hand, spent less than 1% on R&D. Conversely, the position of Japan may be surprising, because it is seen as one of the most innovative countries in the Asia Pacific region; however, it has among the highest R&D spending, which is more than 3% of GDP. As confirmed by quantitative research, high R&D spending funds does not produce proportionally larger results. This study additionally proves that increased spending on innovation causes non-proportional effects. R&D spending should be increased gradually to obtain optimal results. It is also worth to noting that the DEA methodology calculates relative efficiency, which examines the degree to which R&D expenditure has been transformed into potential innovation.
6. Conclusions

The results of the study complement the comparative analysis of ASEAN economies and provides new empirical material with which we can explain the innovation gap between countries. The paper gives a general overview of the level of innovation in ASEAN countries as compared with other Asia Pacific countries. Among all analysed countries, the CRS approach revealed the efficiency frontier as being Hong Kong and, in the case of ASEAN countries, the Philippines. The analysis also showed that among the ASEAN countries, the closest to being an efficiency frontier using the CRS approach are Indonesia, Thailand and Singapore, with Vietnam and Malaysia being less efficient. According to the VRS approach, however, the most efficient countries were Hong Kong, Indonesia, Singapore and the Philippines. According to the VRS model, Korea (0.961) is the closest to an efficiency frontier, and needs reduce its resource usage to 0.039% to become fully efficient. However, Korea also achieved a poor result in the CRS model, which is why it sits in sixth place in the ranking. Hong Kong, as argued by Wang [41], is an example of a country with a positive non-intervention policy aiming to minimise the government’s influence on the market. Thus, while industry innovation is less active in Hong Kong, local industry nonetheless possesses a dynamic innovation base provided by smaller enterprises, most of which develop self-financed spontaneous innovation to provide a solid foundation in an innovation-based economy. Therefore, while lagging behind the other economies, starting with Singapore in terms of R&D expenditure and patent statistics, enterprises in Hong Kong demonstrate high innovation potential. Empirical results for China and India proved to be comparatively poor; although the first of these ranked second in absolute terms, with an annual contribution of over 2% of GDP, China lags behind other developed economies in terms of technology and innovation, especially when considering payments for intellectual property. As outlined in the Made in China 2025 development plan, there is a need to respond to the revolution in such fields as big data, artificial intelligence, the digitisation of conventional industries, robotics and cloud computing through joint efforts by the government, academia and industry, as well as smart manufacturing [11]. Such efforts might help to advance the country from the status of an imitative latecomer in technology, to an innovation-driven knowledge economy. On the other hand, the Make in India program emphasises the creation of clusters to synergise the potential of numerous smaller entities in India; however, there is still a problem with the lack of any long-term strategy or policy for higher education. As a result, there are many obstacles related to a lack of autonomy in governance, employment, intersecting disciplines, creativity bottlenecks, the segregation of teaching and research in STI-related institutions in India, accompanied by inadequate R&D expenditure.

ASEAN as a whole attempts to establish a region-wide innovation policy to make South East Asia an innovation hub. An important platform of cooperation is the ASEAN Committee on Science and Technology, under which there is the possibility of promoting innovation entailing cross-regional synergies. Potential initiatives include:

- innovation surveys or censuses for the use of innovation infrastructure across AMS;
- R&D platforms and databases to be used by regional agencies and institutes to promote and exchange findings; and
- the coordination of R&D scholarship/grant/subsidies schemes, training and education programs across AMS.

This should enhance less-developed AMS to establish NIS. Furthermore, it is necessary to further liberalise and deregulate goods, services and the flow of capital (including ASEAN Framework Agreement on Services, ASEAN Trade in Services Agreement, ASEAN Plus FTAs and RCEP) to stimulate R&D expenditure under international competitive pressure. Last but not least, the freer movement of natural persons would encourage innovation development in ASEAN thanks to knowledge spill-overs. In this regard, regulatory reforms in the field of engineering services are crucial, as well as closer cross-regional collaboration among universities to strengthen the innovation ecosystem of South East Asia.
Despite the many efforts of ASEAN countries, several factors limit their capacity to improve their innovativeness, and hence their economic and social development. For example, with the exception of Singapore, funding across ASEAN countries is consistently low. The Philippines is among the most efficient of ASEAN countries, which was the first to implement NIS in the late 2000s. Indonesia also is close to an efficiency frontier. On the other hand, the position of Singapore, which is the most advanced in terms of NIS implementation and is one of the most developed counties in ASEAN, may be surprising. The evidence presented in this research documents the relative underperformance of the ASEAN region in innovation efficiency. Despite the small amounts spent on innovation, the results are not proportional. As mentioned previously in the methodology section, the research efficiency indicator explores the efficiency of R&D funding usage; therefore, countries with the highest efficiency score do not necessarily achieve the best innovative results. In ASEAN and the Asia Pacific countries, innovative capacities are still limited, and it would thus seem reasonable to gradually increase R&D spending, which in turn may produce better conditions for innovation-driven growth. The results of this study offer important insights for assessing and shaping innovation policies across the ASEAN region. However, it should be noted that results are very general to make concrete recommendations for the development of the NIS in the specific country. Individual country recommendation should also consider the impact of the development level of the country, the sectoral structure of the economy and time lag factor on the innovation input-output relationship.

International institutions are increasingly working towards extending the current statistics on innovation inputs, such as the stock of knowledge, human resources and research infrastructure. However, the current statistics tend to disregard actual innovation outcomes. Enterprises can transform innovation inputs into intermediate outputs, such as patents, and then into innovation outcomes. Innovation outcomes are the economic results of the introduction of innovation and should be taken into consideration, as patent applications themselves do not automatically result in economic outcomes. Ensuring the adequate measurement of innovation outcomes at the country level may require significant structural upgrading [42]. Moreover, the correct estimation of the time lag between transforming inputs into outputs should be taken into consideration. Such statistics, however, are not currently available. Should they become available, their inclusion in the DEA methodology may provide more a reliable overview of the level of efficiency in the economy.

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