Science and Engineering Knowledge Production in ASEAN: Global Emergence, Fading Regionalism

Pieter E. Stek

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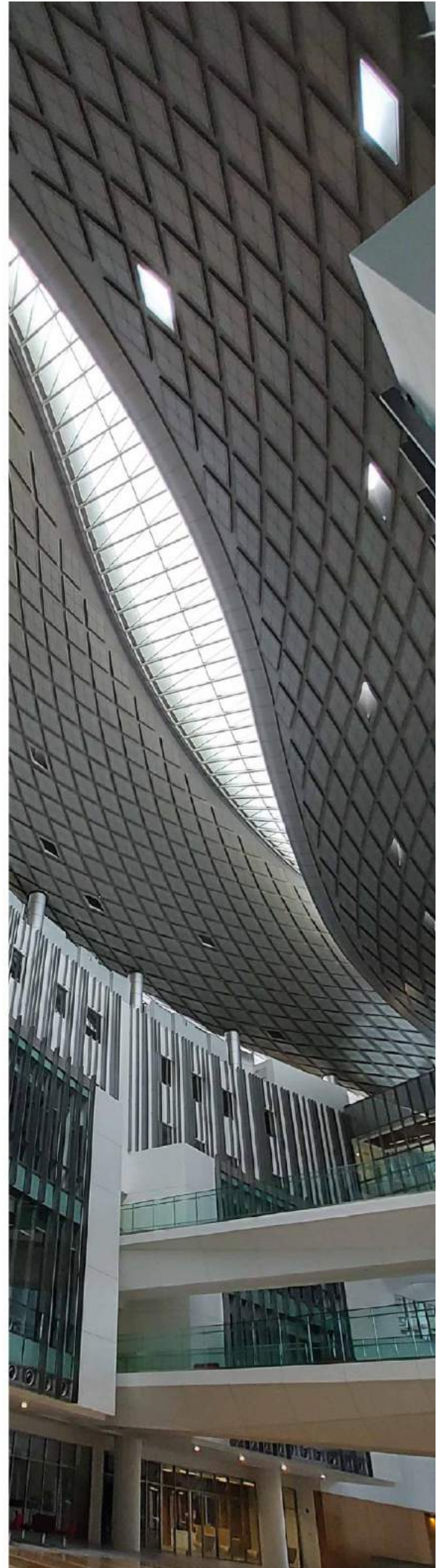
[ABSTRACT / EXECUTIVE SUMMARY]

The ASEAN member states have rapidly increased their global share of science and engineering knowledge production during the past 20 years, from 0.65% in 1996-2000 to 2.8% in 2016-2020. However, the growth in knowledge production has been unequal, and has occurred during different periods of time in different member states. The growth in knowledge production has also been accompanied by significant shifts in the knowledge production profile of individual ASEAN member states, both in terms of quantity and quality, and a transformation of their international research collaboration networks. Using a new open-source dataset of nationally aggregated scientometric indicators extracted from the Scopus database, and applying the concept of revealed comparative advantage, the study documents how ASEAN regionalism is fading and how it is being replaced with a broader Asian regionalism in international research collaborations, in which some, but not all, ASEAN member states are participating. The study also highlights the different growth paths of the major ASEAN knowledge producers, and the region's re-orientation away from more nature- and healthcare-focused research, and towards more manufacturing industry-relevant applications. Overall, the knowledge production profiles of ASEAN member states are becoming less similar. In comparing ASEAN to the European Union, the research shows that knowledge production in ASEAN is more global in orientation, and lacks strong policies at a regional level, which might increase convergence and integration within the ASEAN region.

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Pieter E. Stek (pieter.stek@asb.edu.my)
Asia School of Business
11, Jalan Dato Onn
50480 Kuala Lumpur, Malaysia
Tel. +60 3 2023 3158

ABSTRACT

The ASEAN member states have rapidly increased their global share of science and engineering knowledge production during the past 20 years, from 0.65% in 1996-2000 to 2.8% in 2016-2020. However, the growth in knowledge production has been unequal, and has occurred during different periods of time in different member states. The growth in knowledge production has also been accompanied by significant shifts in the knowledge production profile of individual ASEAN member states, both in terms of quantity and quality, and a transformation of their international research collaboration networks. Using a new open-source dataset of nationally aggregated scientometric indicators extracted from the Scopus database, and applying the concept of revealed comparative advantage, the study documents how ASEAN regionalism is fading and how it is being replaced with a broader Asian regionalism in international research collaborations, in which some, but not all, ASEAN member states are participating. The study also highlights the different growth paths of the major ASEAN knowledge producers, and the region's re-orientation away from more nature- and healthcare-focused research, and towards more manufacturing industry-relevant applications. Overall, the knowledge production profiles of ASEAN member states are becoming less similar. In comparing ASEAN to the European Union, the research shows that knowledge production in ASEAN is more global in orientation, and lacks strong policies at a regional level, which might increase convergence and integration within the ASEAN region.

KEY WORDS

Publication profiles, S&E knowledge production, research collaboration, dynamic evolution, ASEAN

1. INTRODUCTION

The member states of the Association of South East Asian Nations (ASEAN) have seen a rapid increase in knowledge production during the past 20 years. During 2016-2020 the ten ASEAN member states produced 2.8% of the world's science and engineering articles (364,379 articles), as compared to 0.65% of articles just two decades prior (33,036 articles during 1996-2000) (White 2021). However, ASEAN's knowledge production remains small compared to its 8.4% of the world population (664 million people in 2021) and 3.5% of world economic activity (US$3.35 trillion[1]) (ASEAN Secretariat 2022).

During the same period, ASEAN has seen a number of regional economic initiatives, including the creation of the ASEAN Economic Community (AEC) in 2003. The AEC was primarily set up to make the region more attractive to foreign direct investment, and to promote international trade (Plummer and Cheong 2009; Ishikawa 2021). These economic policies have led both to an increase in intra-ASEAN economic integration *and* to an increase in the global integration of individual ASEAN member states. This phenomenon reveals itself in areas such as international trade (Lun and Hoffmann 2016), stock market movements (Lim 2009; Lestari 2020), and business cycles (Sethapramote 2015).

This paper explores knowledge production in ASEAN member states from the perspective of ASEAN regional integration. Previous research showed that factors such as scientific, economic, geopolitical and cultural factors influence international research collaboration (Hou, Pan, and Zhu 2021; Jeck and Baláž 2020). Furthermore, evidence from the European Union shows that economic and political integration lead to the convergence of national knowledge production profiles and the strengthening of intra-regional research collaboration networks (Makkonen and Mitze 2016; Grančay, Dudáš, and Mura 2022). In the case of ASEAN, such integration appears to be lacking, as innovation policies at the regional level remain weak

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[1] Gross domestic products at current exchange rates (2021)

(Degelsegger-Márquez, Remøe, and Trienes 2018), and intra-regional research collaboration has been declining from 1979-2010 (Kumar, Rohani, and Ratnavelu 2014). This leads to the main research question of this study: *How has knowledge production and research collaboration developed in the ASEAN region, and to what extent is there a tendency towards regional integration and convergence?*

This study uses a new dataset from the National Center for Science and Engineering Statistics (NCSES) in the United States (White 2021), which contains nationally aggregated scientific publication, research collaboration and citations data, including for all, or a number of ASEAN member states. The study addresses the research question through the lens of revealed comparative advantage: a relative indicator of knowledge output, research quality, and research collaboration, which is more suitable for comparative research (Fink et al. 2013; Grančay, Dudáš, and Mura 2022). It is also an approach that the author believes has not previously been applied to analyze knowledge production in the ASEAN region. Based on this analytical approach, the following research sub-questions are addressed:

1. How has the knowledge output of ASEAN member states developed from 1996 to 2020?
2. What are the revealed comparative advantages of science and engineering research in ASEAN member states, and how have they changed from 1996 to 2020?
3. How have the international research collaboration networks of ASEAN member states changed from 1996 to 2020?
4. To what extent do ASEAN regionalism and globalization influence the knowledge production and research collaboration of ASEAN member states?

This paper begins with a review of the literature about knowledge production in the ASEAN region (section 2). This is followed by a description of the methodological approach and the data used in this study

(section 3). The results of the scientometric analysis are then presented (section 4), leading to a summary of the findings, conclusion, and research limitations (section 5).

2. KNOWLEDGE PRODUCTION IN THE ASEAN REGION

Knowledge production in the ASEAN region has received some attention in the academic literature, although much less than knowledge production in the European Union.[2] Research on ASEAN has addressed various topics, including: the economic significance of knowledge production in ASEAN, international knowledge spillovers, the lack of regionalism, the importance of policies and institutions, and research efficiency. The relevant literature regarding these topics is briefly discussed in this section.

Among ASEAN countries, government R&D expenditure is highly correlated to other key economic indicators related to the development of a knowledge-based economy, including total factor productivity, labor productivity, and production of high technology production (Afzal, Mansur, and Sulong 2017; Kimura, Wong, and Ambashi 2019). There is also a strong relationship between scientific research and the knowledge intensity of economic activity (Nguyen 2011).

Furthermore, exports and non-capital imports from advanced industrialized economies through foreign direct investment are a key knowledge spillover channel for ASEAN economies. However, only countries with the necessary institutional quality are able to benefit from these spillovers, leading to increases in total factor productivity (Dogan and Wong 2020).

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[2] As an example, a search on the website of the journal *Scientometrics* (https://www.springer.com/journal/11192) shows 557 results for "European Union" and 252 articles for "ASEAN" OR "South East Asia" OR "Southeast Asia". *Research Policy* (https://www.sciencedirect.com/journal/research-policy) shows 542 results for "European Union" and 87 results for "ASEAN" OR "South East Asia" OR "Southeast Asia" (accessed 24 March 2023).

Similarly, the development of R&D activities require policy support, and government interventions can enhance the technological significance and scope of innovation that takes place in ASEAN economies. (Wang 2018; Rasiah 2018)

Despite the importance of policy in increasing R&D activity, regional innovation policy at the ASEAN level remains weak, and there is little evidence of regional integration of knowledge production, neither in commercial R&D activity, nor in basic scientific research (Payumo and Sutton 2015; Degelsegger-Márquez, Remøe, and Trienes 2018; Lorenzo 2022). Intra-regional scientific research collaboration appears to be in decline (Kumar, Rohani, and Ratnavelu 2014).

Comparative research on the efficiency of knowledge production in different ASEAN economies show that high-innovation expenditure economies, such as Singapore, and low innovation expenditure economies, such as Indonesia and The Philippines, frequently have the highest return on R&D investment (Afzal and Lawrey 2014; Dobrzanski and Bobowski 2020).

From an economic perspective, ASEAN countries can be divided into several different groups. There is a lower income, but high-growth group of countries, namely Burma, Cambodia, Indonesia, Laos, Philippines and Vietnam. There is also a higher income but low-growth group of countries, namely Brunei, Malaysia, Singapore and Thailand. Among this latter group, Malaysia and Thailand are of particular concern due to their stagnant total factor productivity and the related risk of falling in a so-called 'middle income trap', whereby growth stagnates and countries fail to progress beyond upper middle-income status due to an inability to develop the innovation capacity needed to support higher value-added economic activities (Griffith 2011; Kimura, Wong, and Ambashi 2019).

Largely missing from the above analyses of knowledge production in the ASEAN region are studies on the revealed comparative advantages of knowledge production, and international research collaboration networks. Both are addressed in this paper.

3. METHODOLOGICAL APPROACHES AND DATA

The question of regionalism in ASEAN knowledge production can be approached from several different angles, including the similarities between the knowledge production profiles of countries (regional convergence), and the extent to which these countries are more strongly connected through international research collaborations (regional integration).

Regional convergence can be identified based on the similarity of the knowledge production profiles of ASEAN member states. A high degree of similarity indicates high convergence. Due to the large differences in size and economic development level, it is useful to compare states based on relative indicators. The relative comparative advantage was originally proposed for the purpose of comparing the trade specialization of countries (Balassa 1977), but has since been applied in scientometric studies as well (Fink et al. 2013; Mansourzadeh et al. 2019; Grančay, Dudáš, and Mura 2022). In addition to calculating the revealed comparative advantage index for knowledge production (i.e. number of papers), the index has also been applied to measures of the quality of papers, such as the number of citations (Fink et al. 2013), or the number of papers published in the top-1% most highly cited academic journals (White 2021).

The knowledge production index ($RCAP_{ij}$) is calculated as follows, whereby P is the number of papers, i is a particular knowledge field, j indicates countries and w the world total (Fink et al. 2013). If $RCAP_{ij} > 1$, the country has a higher share of research activity in a particular sector than the global average.

$$RCAP_{ij} = \frac{P_{ij}/\sum P_{ij}}{P_{iw}/\sum P_{iw}} \tag{1}$$

The knowledge quality index ($RCAQ_{ij}$) is calculated based on the number of publications T from knowledge field i and country j appearing among the top-1% most cited academic journals compared to the total number of articles P from knowledge field i and country j (White 2021). If $RCAQ_{ij} > 1$, the country produces more high-quality research papers than the global average in a particular knowledge field.

$$RCAQ_{ij} = T_{ij}/P_{ij} \tag{2}$$

As the knowledge production index and knowledge quality index are calculated for multiple sectors, a Pearson correlation can be used to analyze the degree of similarity in knowledge output of ASEAN member states.

In addition to regional convergence, regional integration is also explored in this study. Evidence of regional integration comes from international research collaboration, and an international research collaboration index ($RCAC_{jk}$) which expresses the number of internationally co-authored papers C of a country j with country k, relative to the total number of international research collaborations of these countries and the world w (White 2021). This relationship is expressed in equation 3.

$$RCAC_{jk} = \frac{C_{jk}/C_j}{C_k/C_w} \tag{3}$$

The collaboration index network of ASEAN member states can be visualized using the *igraph* package in R (Csardi and Nepusz 2006).

The data used to calculate the aforementioned indexes is obtained from the very extensive supplementary tables of the *Publications Output: U.S. Trends and International Comparisons*[3] from the NCSES (White 2021). The quality and collaboration indices (RCAQ, RCAC) are already calculated in tables, whereas the knowledge production index (RCAP) is calculated by the author. The supplementary tables are based on Elsevier's Scopus abstract and citation database (accessed May 2021) and are a valuable resource for researchers who, due to resource constraints, do not have access to the Scopus database.

As ASEAN knowledge production has grown rapidly, from 0.65% to 2.8% of world output from 1996-2020, for some ASEAN countries, only very few publications are included in the Scopus database, which limits the validity of any analysis. For this reason, parts of the analysis cover only the ASEAN-5 countries, namely Indonesia, Malaysia, Singapore, Thailand and Vietnam. These are the five ASEAN countries with the highest scientific paper output in recent times.

Finally, this study follows the country nomenclature maintained by the report (White 2021). Brunei refers to Brunei Darussalam, Burma refers to the Union of Myanmar, and Laos refers to the Lao People's Democratic Republic (Lao PDR).

4. RESULTS AND ANALYSIS

The results and analysis suggest that in all aspects, ASEAN regionalism is weakening: the knowledge output profiles of ASEAN member states are diverging, and international research collaborations are increasingly global in orientation, at the expense of intra-ASEAN research collaboration. The most rapid globalization of knowledge production appears to be occurring in Singapore, while at the same time

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[3] The supplementary tables of the report can be accessed via https://ncses.nsf.gov/pubs/nsb20214/data (accessed 24 March 2023)

Indonesia is the country which is moving towards regionalism by deepening its research ties with other ASEAN-5 countries.

An in-depth analysis of these trends is presented in this section, starting with changes in knowledge output among ASEAN member states (subsection 4.1), and then followed by the divergence in knowledge output profiles (subsection 4.2) and changes in international research collaborations (subsection 4.3).

4.1 Knowledge Output of ASEAN Member States
The rapid growth of science and engineering knowledge production in ASEAN member states is shown in figure 1. During the 1990s, Singapore, followed at some distance by Thailand and Malaysia, were the largest knowledge producers in the ASEAN region. However, between 2008-2011, Malaysia overtook Thailand and then Singapore, to become the region's largest producer of science and engineering publications (papers and conference proceedings), following a trend of rapid growth, which started in 2007.

By the mid 2010s, Indonesia experienced a rapid growth in publication output, leading it to overtake Malaysia in 2018. More modest growth in Thailand, and slowing growth in Singapore, placed Thailand back in third place after 2018, although it is significantly behind Indonesia and Malaysia. As of 2020, Vietnam appears poised to rapidly increase its publication output as well.
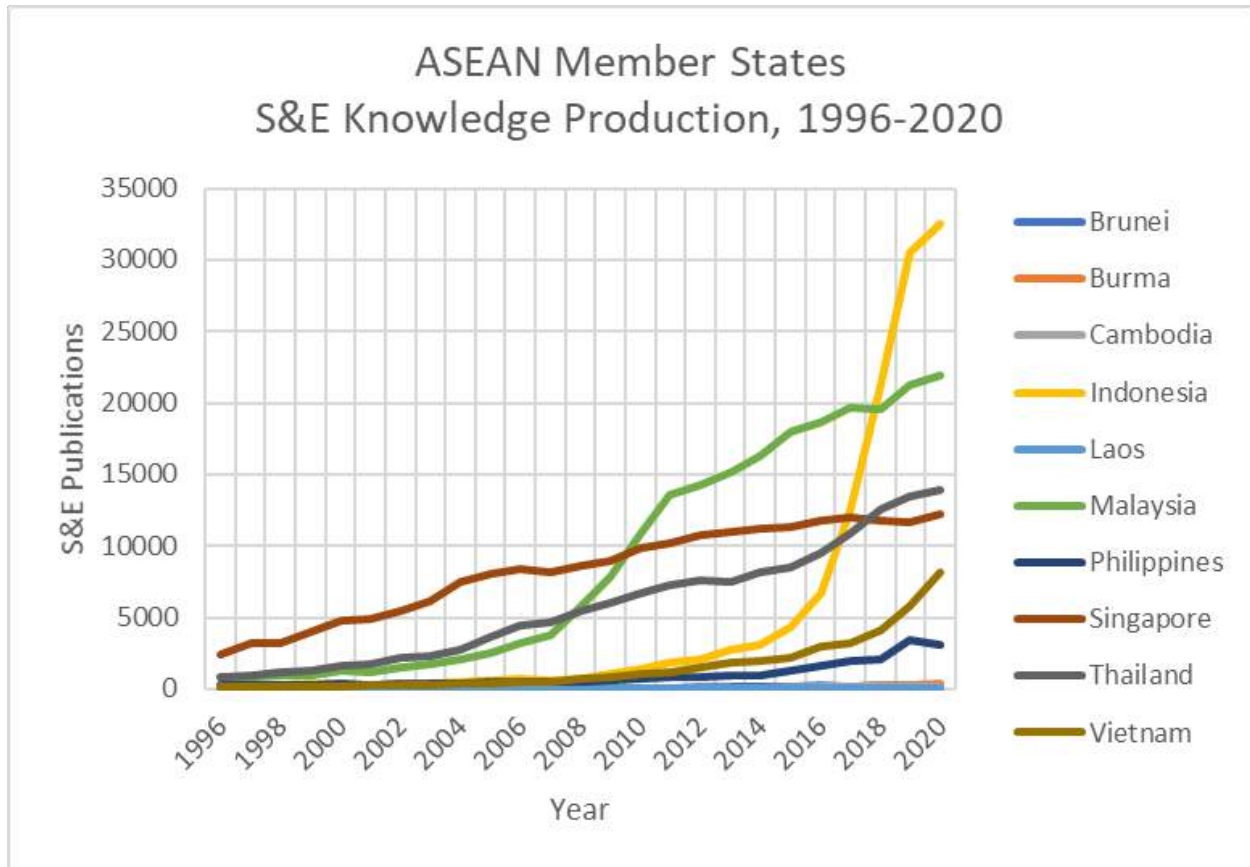
Figure 1: Science and engineering knowledge production of ASEAN member states, data source: White (2021)

The increase in science and engineering publishing in Malaysia is related to a significant increase in the research budget of its universities (Department of Higher Education 2019). The increase in academic publishing in Indonesia is related to a change in government policy that rewarded academics for international publications (Putera et al. 2022), and has also coincided with a rapid increase in international conference participation by Indonesian academics (Fry, Lynham, and Tran 2023; Purnell 2021).

Despite five ASEAN member states ("ASEAN-5") producing more than 5,000 science and engineering publications annually by 2020, the other five ASEAN member states have published significantly lower numbers, with 287 from Brunei, 419 from Burma, 166 from Cambodia, 89 from Laos and 3,072 from The Philippines.

Although Indonesia became the largest science and engineering knowledge producer in 2018, measures of the average quality of scientific output place Singapore at the top of the ASEAN region (see figure 2). In fact, Singapore has more than twice as many publications among the 1% most-cited compared to the global average. Vietnam and Malaysia produce scientific papers which are around the global average in terms of citations in 2020, whereas papers from Thailand and Indonesia are well below the global average.

It is notable that Singapore has increased *both* the number of publications *and* their average quality during the study period. This is in contrast to Indonesia, where the quality of knowledge production has declined amid an increase in publications. Malaysia has kept a more-or-less constant quality of knowledge production since starting its higher-growth phase in 2008, and Vietnam also appears to be combining growth with improving or stable quality from 2015-2018. The reasons for this difference may be linked to diverging research policies. It appears that the rapid increase in science and engineering publications from Indonesia has not been accompanied by a major increase in public research expenditure, but rather a change in how academic staff are evaluated (Tilley and Hidayat 2017; Fry, Lynham, and Tran 2023).
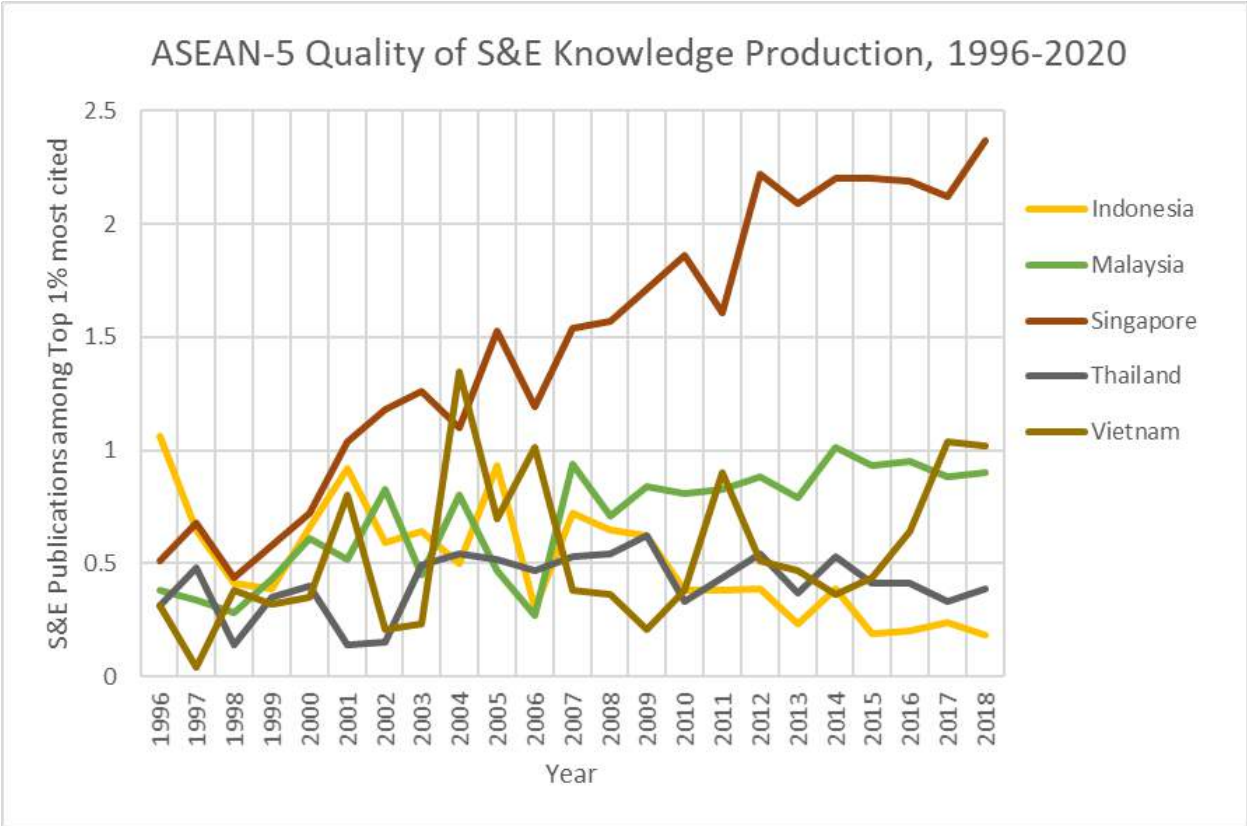
Figure 2: Science and engineering knowledge quality of ASEAN-5 countries, data source: White (2021)

4.2 Knowledge Output Profiles of ASEAN Member States

Aside from changes in the overall quantity and quality of science and engineering knowledge production,

there is also a shift in the orientation of knowledge production by ASEAN member states. There is a

growing focus on knowledge fields related to industrial sciences, and a decline from more nature and

healthcare-related fields. In the meantime, only a selected group of three ASEAN member states

(Singapore, Malaysia and Vietnam) were able to increase by more than two, the number of knowledge

fields in which they have a quality-based revealed comparative advantage. Overall, the correlation

between national knowledge output profiles of ASEAN member states is declining.

Table 1 shows that, as ASEAN member states have further industrialized, they have re-oriented their

knowledge production towards industrial sciences, including chemistry, computer and information

science, engineering and materials science. In 1996-2000 only Malaysia had a revealed comparative

advantage in Chemistry; Malaysia, Singapore and Thailand had an advantage in computer and information science; Indonesia, Singapore and Thailand had an advantage in Engineering, and only Singapore in Materials.

By 2016-2020, Singapore, Thailand and Vietnam added a revealed comparative advantage in chemistry; Brunei, Burma, Indonesia, Philippines and Vietnam in computer and information systems; Brunei, Malaysia and Vietnam in engineering (but Thailand losing), and Brunei, Malaysia, Thailand and Vietnam in materials (but losing Singapore).

During the same period, ASEAN member states lost some of their knowledge production comparative advantages in nature- and healthcare-related fields: one country in biological and biomedical sciences and natural resource and conservation; three countries in geosciences and related, and two countries in health sciences. Mathematics and psychology also lost one country each, while the number of countries with a revealed comparative advantage in agricultural science remained unchanged. These observations highlight the growth of more manufacturing-relevant research, while the emphasis on agriculture has remained constant.

Knowledge Field	1996-2000	2016-2020	Change
Agricultural sciences	7	7	-
Astronomy and astrophysics	0	0	-
Biological and biomedical sciences	4	5	-1
Chemistry	1	4	+3
Computer and information science	3	8	+5
Engineering	3	5	+2
Geosciences and related	6	3	-3
Health sciences	4	2	-2
Materials science	1	4	+3
Mathematics	3	2	-1
Natural resources and conservation	9	8	-1
Physics	2	3	+1

Psychology	1	0	-1
Social sciences	6	7	+1

Table 1: Number of ASEAN member states with a revealed comparative advantage (knowledge production) in a particular knowledge field during 1996-2000 and 2016-2020.

As already evident from figure 2, there are large differences in the research quality profiles of ASEAN member states, and this is also confirmed by the figures presented in table 2. In 2016-2020 Brunei, Burma and Indonesia do not have a quality advantage in a single knowledge field, whereas Vietnam has two, Malaysia has four, and Singapore has 12. The shift in terms of quality is most dramatic in Singapore (adding 9 fields) and Indonesia (losing 5 fields. Malaysia and Vietnam both see an increase of two fields, showing that Singapore, followed at a great distance by Malaysia and Vietnam, have the highest quality national research and innovation systems.

Complete data of revealed comparative advantages, for quantity and quality, are provided in table A1 and A2 of the appendix.

Country	1996-2000	2016-2020	Change
Brunei	0	0	-
Burma	0	0	-
Cambodia	0	1	+1
Indonesia	5	0	-5
Laos	0	1	+1
Malaysia	2	4	+2
Philippines	2	1	-1
Singapore	3	12	+9
Thailand	1	0	-1
Vietnam	0	2	+2

Table 2: Number of sectors in ASEAN member states with a revealed comparative advantage (quality) during 1996-2000 and 2016-2020.

The shift in orientation of ASEAN member states' knowledge production systems has resulted in decreasing similarity in their knowledge output profiles. As shown in table A3 and A4 in the appendix,

Cambodia, Indonesia, Laos, Malaysia, The Philippines and Thailand had relatively similar knowledge output profiles in 1996-2000, with a Pearson's R^2 > 0.5. During this time, Singapore was already a major outlier, having low or negative correlations with almost all other ASEAN member states.

By 2016-2020, the pattern of correlations has become more complex. Thailand has a high correlation with Laos and Malaysia, The Philippines with Brunei and Burma, Laos with Cambodia and Thailand, and Malaysia with Indonesia. This suggests that the knowledge production profiles of ASEAN member states are diverging and becoming more dissimilar. Singapore and Vietnam continue to have below R^2 < 0.5 correlations with all other ASEAN member states.

At a macro-ASEAN regional level, between 2006-2000 and 2016-2020, the correlation of knowledge production revealed comparative advantages fell from 0.30 to 0.26, and the number of country-pairs with a correlation of R^2 > 0.5 declined from 15 to 6 (see also tables A3 and A4 in the appendix).

4.3 International Research Collaboration of ASEAN Member States
Aside from similarities in their research profiles, a preference for research collaboration within the region is also an indicator of regional integration (Makkonen and Mitze 2016; Jeck and Baláž 2020). Based on the international research collaboration index described in section 3, the international research collaboration network of the ASEAN-5 countries shows a strong regional network in 1996 (see figure 3, collaboration index > 1.5 is shown). During this time, Malaysia, Thailand, Indonesia and Vietnam form close relations with each other, with Singapore being most strongly connected to Malaysia. Other countries with strong research links to the ASEAN network include China, India, Australia and Japan, countries located within the Asia and Pacific region. At a greater geographic distance, The Netherlands, United Kingdom and Sweden are also shown, although they only maintain close ties to a single ASEAN-5 state.

The strong relationship between Colombia and Vietnam may seem surprising, but it must be noted that during 1996, the science and engineering knowledge production of Vietnam was very small (178 papers), and so only a few papers with co-authors from Colombia are needed to create a strong network link. This is a consequence of using relative indicators, and it should be taken into account when interpreting these results.
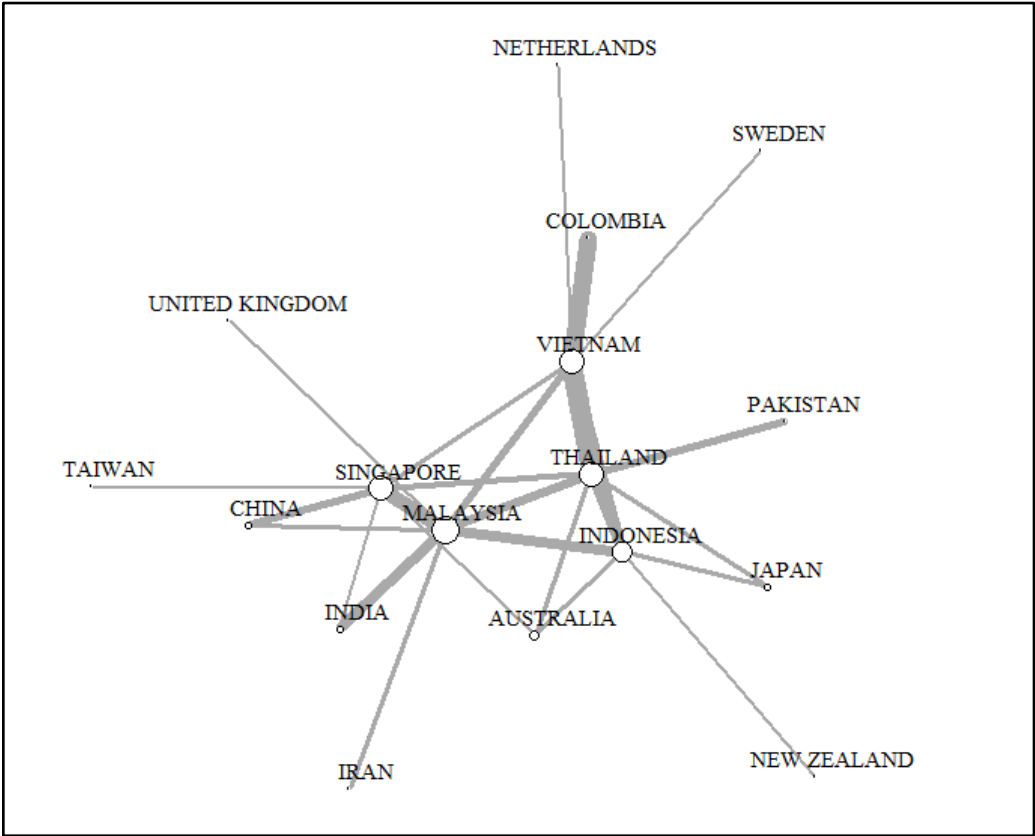
Figure 3: Relative international co-authorship network of ASEAN-5 (1996)

The ASEAN-5 co-authorship network looks significantly different in 2020 (figure 4, collaboration index > 1.5 is shown). Vietnam andIndonesia have taken up a much more prominent position in the network, and several non-ASEAN economies have become closely integrated into the ASEAN-5 network. These include Taiwan, South Korea, Japan, India, Iran, Pakistan, Turkey and Saudi Arabia. In fact, Vietnam's co-authorship with other ASEAN member states has weakened considerably, but its collaboration with different non-ASEAN economies has increased. By contrast, Indonesia has some of the strongest links to

other ASEAN countries and is the main intra-ASEAN hub. In 1996, the strongest intra-ASEAN relations were Thailand-Vietnam (8.85) and Malaysia-Singapore (6.34). By 2020, this changed to Malaysia-Indonesia (10.59) and Thailand-Indonesia (4.75).

Singapore has largely left the ASEAN-5 network, as is clearly shown in the network graph (figure 4). Australia, which was closely connected to Singapore, Thailand and Indonesia in 1996, also no longer appears in the network.

In this sense, the ASEAN-5 research collaboration network has transformed into a larger pan-Asian research network, which is focused both on north Asian economies (Japan, South Korea, Taiwan) and south and west Asian economies (India, Pakistan, Iran), with Vietnam and Indonesia at its center. Singapore has developed a less regional and more globally focused research collaboration profile, and is the only country in the network with a strong focus on China, Asia's largest economy. The relatively remote position of China in the ASEAN research network is somewhat surprising, given that China is a neighboring country and one of the largest trade and investment partners of ASEAN (ASEAN Secretariat 2022).
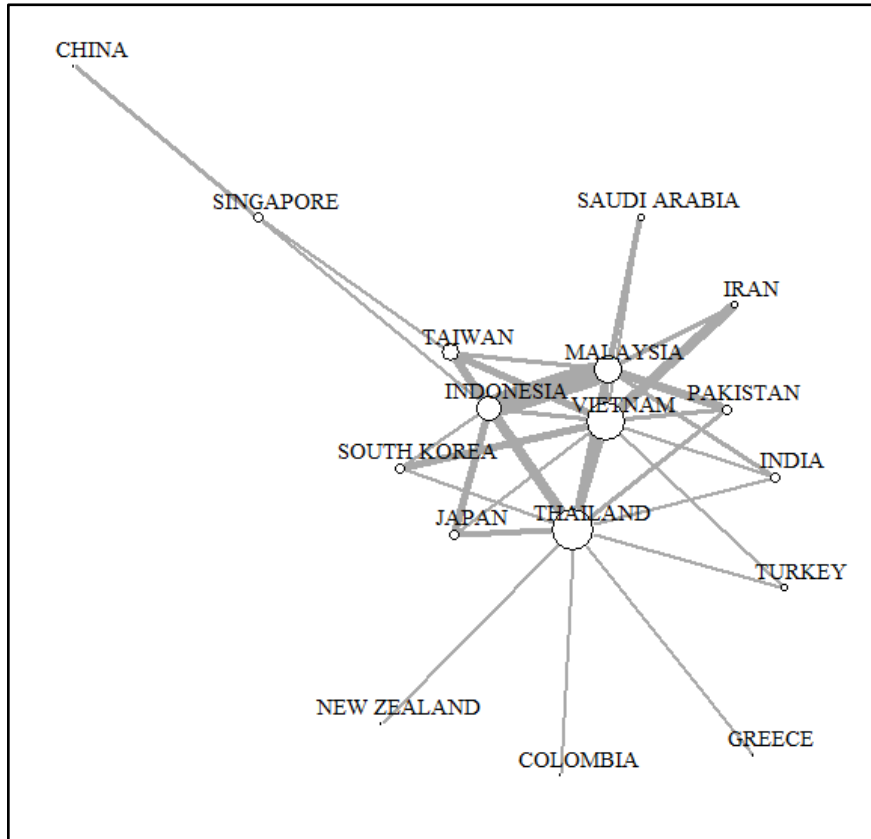
Figure 4: Relative international co-authorship network of ASEAN-5 (2020)

5. DISCUSSION, CONCLUSION AND LIMITATIONS

The results of this study show that some ASEAN member states have experienced a large increase in science engineering knowledge production during the study period. This growth has occurred in waves, starting with Singapore, then Malaysia, and then Indonesia and to a lesser extent Thailand, with Vietnam taking off in the late 2010s. The growth appears to be policy-driven, and has sometimes led to a decline in research quality, specifically in Indonesia. Singapore has emerged as the ASEAN member state with the highest quality research output.

The knowledge production profiles of the ASEAN member states have generally shifted away from nature- and healthcare-focused research and towards industrial technologies. The countries have also become more dissimilar in their knowledge production profiles. In terms of their comparative advantages in

research quality, only Singapore, Malaysia and Vietnam have seen an increase of two or more knowledge fields where their research output is of higher quality than the global average.

The ASEAN research collaboration network has also been transformed, from a more narrowly Southeast Asia-centric network in 1996 to a more broadly Asian network in 2020, which includes states in northern and south and west Asia. Vietnam plays a central role in this network, along with Indonesia. Singapore has reduced its Asian focus in its research collaborations, with the exception of China. Singapore has the most globally balanced research collaboration network of all ASEAN-5 member states.

The declining similarity in knowledge production profiles, as viewed from the perspective of revealed comparative advantage, and the re-orientation of the international research collaboration network towards a broader Asian geography, suggests that ASEAN regionalism is in decline.

This development appears to be part of a long-term trend (Kumar, Rohani, and Ratnavelu 2014; Degelsegger-Márquez, Remøe, and Trienes 2018), and it contrasts with the greater research convergence and integration observed in other regions, such as the European Union (Makkonen and Mitze 2016; Grančay, Dudáš, and Mura 2022). However, the European case differs significantly from ASEAN, not least because there is a centralized European Union science policy, and because economic and human development levels among European Union member states are relatively similar, when compared to ASEAN.

Although the results show a decline of ASEAN regionalism in knowledge production, the results also show that ASEAN is becoming part of a broader Asian knowledge production system, likely driven by a combination of scientific, economic, geographic and cultural factors, rather than by government policies

(Hou, Pan, and Zhu 2021). In the same way that ASEAN countries have benefited from being a part of global supply chains, even though they are at different stages of economic development, it is possible that the different knowledge production profiles of its member states compliment ASEAN's overall knowledge production efforts. In this sense, it may be fruitful to look at regionalism in South East Asian science through a broader geographic and analytical lens.

The study also showed the different paths followed by the ASEAN-5 member states, namely Singapore, Malaysia, Indonesia, Thailand and Vietnam. Each appears to have followed distinct policies at different times, which have increased knowledge production in different ways. Singapore has largely 'escaped' the region in terms of research collaboration and quality. Indonesia has become the largest producer and the central node within the ASEAN knowledge production system. Malaysia has experienced a rapid increase, like Indonesia, whereas Thailand has grown more gradually. Vietnam is fast emerging as a large knowledge producer within ASEAN, although it is less integrated into the ASEAN region from a knowledge profile and network perspective. These differences highlight the diversity of the region, and the potential for future comparative research.

The study also has a number of limitations. The study uses ASEAN member states as the unit of analysis, whereas research tends to be highly spatially concentrated into clusters (Malecki 2021). The study uses only a single source of data, science and engineering publications, whereas additional sources of data, such as patents, may provide further insights. A broader understanding of ASEAN regionalism in knowledge production may also benefit from a more detailed analysis of the policy frameworks, R&D funding and mobility of researchers in ASEAN member states. However, this is an area of inquiry that is beyond the scope of this paper.

APPENDIX

Field of Science	Brunei	Burma	Cambodia	Indonesia	Laos	Malaysia	Philippines	Singapore	Thailand	Vietnam
Agricultural sciences	0.83	0.47	11.93	3.97	8.06	2.63	7.14	0.19	2.01	4.50
Astronomy and astrophysics	0	0	0	0.49	0	0.02	0.13	0.05	0.07	0.09
Biological and biomedical science	0.82	0.82	0.73	1.96	1.16	0.93	1.88	0.42	1.03	0.99
Chemistry	0.59	0.91	0	0.41	0	1.61	0.12	0.70	0.58	0.70
Computer and information science	1.21	0.53	0	0.35	0	1.72	0.35	3.11	0.95	0.65
Engineering	0.71	0.09	0.13	1.10	0.49	0.83	0.30	2.39	1.04	0.89
Geosciences and related	4.83	1.75	0.16	2.52	1.69	0.57	2.84	0.19	0.50	1.33
Health sciences	0.43	2.09	1.68	0.51	1.52	0.98	0.53	0.59	1.52	0.54
Materials science	0.67	0	0	0.75	0.27	0.69	0.09	1.78	0.34	0.55
Mathematics	2.03	0.68	0.12	0.17	0	0.63	0.60	1.30	0.27	6.65
Natural resources and conserv.	2.43	1.04	1.00	4.60	1.90	2.84	7.86	0.56	2.17	1.92
Physics	0.13	0.03	0.10	0.38	0	0.56	0.29	1.11	0.24	1.14
Psychology	0.15	0	0.25	0.29	2.12	0.28	0.38	0.31	0.23	0.07
Social sciences	7.42	0.35	2.68	1.67	0.16	1.29	2.38	1.18	0.71	0.46

Table A1: Revealed comparative advantage (knowledge production) of ASEAN member states, 1996-2000

Field of Science	Brunei	Burma	Cambodia	Indonesia	Laos	Malaysia	Philippines	Singapore	Thailand	Vietnam
Agricultural sciences	0.77	0.85	2.02	1.28	4.44	1.30	1.33	0.22	2.26	1.08
Astronomy and astrophysics	0	0	0	0.02	0	0.02	0	0.02	0.17	0.23
Biological and biomedical science	0.66	1.69	2.56	0.54	2.32	0.77	1.08	0.75	1.32	0.89
Chemistry	0.72	0.16	0.07	0.41	0.05	1.14	0.24	1.07	1.03	1.04
Computer and information science	1.13	3.26	0.29	1.53	0.13	1.41	2.19	1.57	1.15	1.98
Engineering	1.23	0.68	0.42	1.33	0.56	1.13	0.74	1.57	0.89	1.06
Geosciences and related	2.39	1.10	0.82	0.33	1.00	0.53	1.90	0.39	0.39	0.68
Health sciences	0.63	0.87	1.46	0.34	1.29	0.50	0.60	0.78	0.91	0.31
Materials science	1.41	0.16	0.09	0.84	0.19	2.19	0.76	0.81	1.61	1.13
Mathematics	0.36	0.09	0.12	0.18	0.06	0.59	0.83	0.55	1.07	3.47
Natural resources and conserv.	1.34	0.60	1.59	1.48	2.48	1.70	1.78	0.59	1.54	1.51
Physics	0.86	0.13	0.10	3.01	0.03	1.36	0.63	1.00	0.69	1.26
Psychology	0.34	0.16	0.44	0.22	0.33	0.30	0.58	0.73	0.18	0.15
Social sciences	2.65	0.74	1.82	1.05	1.60	1.42	2.21	1.08	0.77	0.89

Table A2: Revealed comparative advantage (knowledge production) of ASEAN member states, 2016-2020

	Brunei	Burma	Cambodia	Indonesia	Laos	Malaysia	Philippines	Singapore	Thailand	Vietnam
Brunei	1	0.24	0.06	0.33	-0.08	0.15	0.29	-0.02	0.04	0.05
Burma	0.24	1	0.01	0.25	0.11	0.22	0.23	-0.29	0.41	0.09
Cambodia	0.06	0.01	1	**0.58**	**0.92**	**0.58**	**0.65**	-0.29	**0.59**	0.42
Indonesia	0.33	0.25	**0.58**	1	0.66	**0.73**	**0.97**	-0.36	**0.76**	0.25
Laos	-0.08	0.11	**0.92**	0.66	1	**0.53**	**0.71**	-0.42	**0.62**	0.38
Malaysia	0.15	0.22	**0.58**	0.73	0.53	1	**0.79**	0.05	**0.85**	0.27
Philippines	0.29	0.23	**0.65**	0.97	0.71	0.79	1	-0.37	**0.78**	0.37
Singapore	-0.02	-0.29	-0.29	-0.36	-0.42	0.05	-0.37	1	-0.07	-0.06
Thailand	0.04	0.41	**0.59**	0.76	0.62	0.85	0.78	-0.07	1	0.20
Vietnam	0.05	0.09	0.42	0.25	0.38	0.27	0.37	-0.06	0.20	1

Table A3: Revealed comparative advantage (knowledge output) correlation, 1996-2000; correlation of > 0.5 in bold.

	Brunei	Burma	Cambodia	Indonesia	Laos	Malaysia	Philippines	Singapore	Thailand	Vietnam
Brunei	1	0.23	0.26	0.22	0.16	0.46	**0.75**	0.27	0.03	-0.04
Burma	0.23	1	0.31	0.16	0.18	0.14	**0.64**	0.43	0.21	0.14
Cambodia	0.26	0.31	1	-0.01	**0.86**	0.07	0.46	-0.18	0.44	-0.20
Indonesia	0.22	0.16	-0.01	1	0.10	**0.61**	0.26	0.43	0.27	0.18
Laos	0.16	0.18	**0.86**	0.10	1	0.18	0.40	-0.35	**0.66**	-0.12
Malaysia	0.46	0.14	0.07	**0.61**	0.18	1	0.39	0.42	**0.66**	0.28
Philippines	**0.75**	**0.64**	0.46	0.26	0.40	0.39	1	0.22	0.26	0.24
Singapore	0.27	0.43	-0.18	0.43	-0.35	0.42	0.22	1	0.00	0.18
Thailand	0.03	0.21	0.44	0.27	**0.66**	**0.66**	0.26	0.00	1	0.36
Vietnam	-0.04	0.14	-0.20	0.18	-0.12	0.28	0.24	0.18	0.36	1

Table A4: Revealed comparative advantage (knowledge output) correlation, 2016-2020; correlation of > 0.5 in bold.

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