BACKGROUND PAPER

Trends and Determinants of Innovation in Asia-Pacific and Latin America and the Caribbean

Irfan Qureshi, Donghyun Park, Gustavo Atilio Crespi, and Jose Miguel Benavente

TRENDS AND DETERMINANTS OF INNOVATION IN ASIA AND THE PACIFIC AND LATIN AMERICA AND THE CARIBBEAN[1]

Irfan Qureshi[2] Donghyun Park[3] Gustavo Atilio Crespi[4] Jose Miguel Benavente[5] [6]

Abstract

We present a comparative analysis of innovation trends and determinants of innovation in the Asia-Pacific region versus the Latin America and the Caribbean region. We sift through several measures of innovation to map out the patterns of innovation in the two regions. The indicators include researcher density, research and development spending, patenting, high-technology exports, economic complexity index, scientific publications and trademark flows. Overall, the stylized facts clearly show that Asia-Pacific innovates more than Latin America and the Caribbean. At the same, there is considerable intra-regional heterogeneity and aggregate regional innovation is driven largely by higher-income countries. More formal empirical analysis based on panel regression techniques shows that investment in R&D, secondary school enrolment, and infrastructure access are the key drivers of innovation. However, these factors are conditional on the type of innovation and on the region.

JEL codes
O30

Keywords
Innovation, Asia, Latin America, R&D, patent

I. INTRODUCTION

Innovation is a key driver of economic growth and development (Aghion and Howitt 1992).[7] However, most empirical analysis on the determinants of innovation at the macroeconomic level has focused on developed countries which are at or near the global technological frontier. Relatively little analysis delves into innovation patterns and on the determinants to innovation in catch-up economies, and even less about differences in patterns of innovation among developing economies.

In this paper, we hope to help reduce this knowledge gap and contribute to the literature by analyzing and comparison in two developing regions, namely the Asian-Pacific (AP) and Latin America and the Caribbean (LAC). The two regions are natural comparator regions because they are broadly at similar income and development levels. While LAC was substantially richer than AP a few decades ago, AP's sustained rapid growth has greatly reduced the income gap. Although at similar income levels, the two regions are also marked by significant differences. For example, in terms of initial factor endowments, AP region had abundant in low-skill labor while LAC region had abundant natural resources. More

[1] The views expressed in this paper are those of the authors alone and do not necessarily reflect the views of the Asian Development Bank (ADB) or the Inter-American Development Bank (IDB), their Boards of Directors, or the countries they represent.

[2] All comments and/or questions should be directed to the corresponding author: Economic Research and Regional Cooperation Department (ERCD), Asian Development Bank, 6 ADB Avenue, Metro Manila, Philippines. Email: iqureshi@adb.org

[3] Economic Research and Regional Cooperation Department (ERCD), Asian Development Bank, 6 ADB Avenue, Metro Manila, Philippines. Email: dpark@adb.org

[4] Principal Specialist, Science and Technology, Inter-American Development Bank. Email: gcrespi@iadb.org

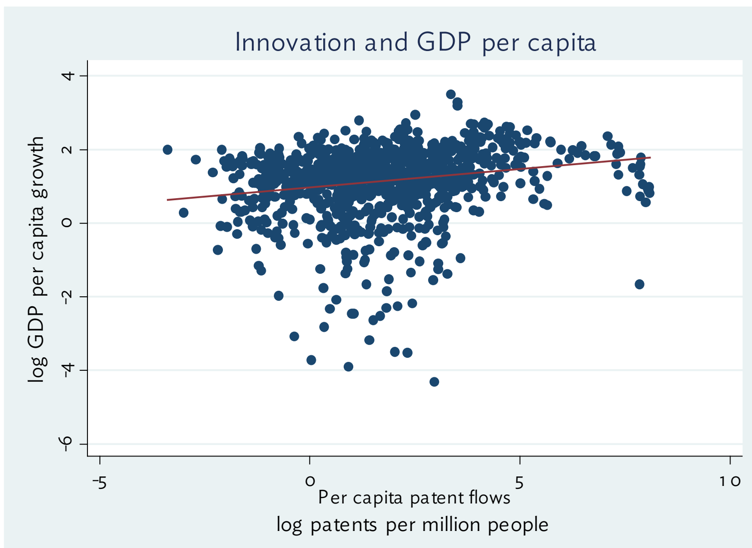
[5] Principal Specialist, Science and Technology, Inter-American Development Bank. Email: jbenavente@iadb.org

[6] We are grateful to Emmanuel Elano and Juan Luis Fuentes for their excellent research support.

[7] Hereinafter called Asia and the Pacific (AP) and Latin America and the Caribbean (LAC).

importantly, AP largely enjoyed macroeconomic stability and pursued outward-looking export-oriented growth strategy, many LAC countries suffered macroeconomic instability and followed inward-looking import substitution growth strategy. But perhaps the biggest difference between the two regions is that AP grew markedly more rapidly than LAC for an extended period of time. In fact, AP has been the world's fastest-growing region for quite some time.

AP is home to well-known innovative tech giants such as Alibaba, Samsung Electronics and Infosys. On the other hand, one would be hard-pressed to name innovative global companies from LAC. Therefore, innovation may be an often-overlooked factor which can help explains the difference in the two regions' economic performance in recent decades. Going forward, innovation holds the key to productivity growth, which assumes a larger role in economic growth at middle income (ADB 2017). Figure 1 illustrates the relationship between innovation (as measured by patents) and GDP per capita growth in the two regions. These variables are positively associated. Therefore, to sustain and maintain economic growth, these economies need to innovate.



In the first part of the paper, we describe the empirical stylized facts pertaining to innovation in AP versus LAC, compare and analyze those facts, and provide a granular understanding of the data. In the second part, we use panel data analysis to identify the determinants of innovation in the two regions. In this connection, several interesting questions emerge. What are the drivers of innovation? Is it the macroeconomy, policies, or institutions? Do the same set of indicators influence innovation in AP and LAC? A key contribution of our analysis to the literature is that there is no such comparative study of innovation for the two regions.

The data used in the study is sourced from the World Bank's World Development Indicators database. We derive trends and patterns from the data to compare the similarities and differences in innovation between AP and LAC, sub-regions, and individual countries. To test for the underlying determinants of innovation trends, we employ regressions using two measures of innovation and a time-series panel data of AP and LAC countries.

Overall, the stylized facts clearly indicate that AP innovates more than LAC. However, there is a lot of heterogeneity across countries. High and upper-middle income countries dominate the rankings and play

a disproportionate role in all major innovation indicators – e.g. researcher density, R&D spending, patents, high-technology exports, economic complexity index (ECI), scientific publications, and trademarks.

To examine what drives innovation in these countries, we apply panel regression techniques on a large set of control variables. We find that the determinants of innovation differ in the two regions. R&D is a significant determinant of patenting in AP but not in LAC. This suggests that has a bigger impact on technological advancements in AP.

Overall, research and development, human capital, infrastructure investment and financial development seem to have a positive and significant impact on innovation rates. However, these factors are conditional on the type of innovation and on the region.

II. RELATED LITERATURE

Endogenous growth models have linked innovation with economic development (Aghion and Howitt 1992) and have factored in the endogenous growth models of Romer (1990) as it enables sustainable economic growth due to constant returns to innovation in terms of human capital employed in the R&D sectors. However, there is still debate on what drives innovative activities. Even less is known about innovation activities in catching-up economies.

At the same time, only a few studies have examined innovation at the aggregate level. Of these, a few include innovation as a determinant of economic growth (and vice versa) in empirical research using either input measures such as research and development expenditure or innovation outputs such as patents. Though an imperfect measure of innovation level, most empirical studies mainly used patents as measure, as technological breakthroughs and inventions often are the results from patents (Kortum 1997). Patents also cover all technological fields and are collected in a relatively comparable way across a relatively large set of countries over a long time period.

Using aggregate patent level data, Stern et al. (2000) find that innovation is positively related to human capital in the R&D sector and the knowledge stock. More specifically, patenting is driven by R&D manpower, spending, policies such as intellectual property protection and openness to international trade. Ulku (2004) finds that the effect of R&D stock on innovation is significant only in Organisation for Economic Co-operation and Development (OECD) countries with large markets. More recently Ang and Madsen (2013) using a large sample of OECD economies provide estimates finding strong intertemporal and cross-country knowledge spillovers in a patent production function, suggesting that human capital and some channels of international knowledge spillovers are influential for ideas production. Table 1 succinctly describes the literature in this area.

Table 1: Empirical Studies on Determinants of Innovation

Study	Innovation Measures	Key Findings	Country Coverage
Stern et al. 2000	International patents granted by US Patent Office	Innovative capacity is characterized by R&D manpower and spending, policies such as protection of intellectual property, trade openness, share of research by academic/private sector, and knowledge “stock”. There is convergence in innovative capacity in some OECD countries.	17 OCED countries from 1973-2006
Ulku 2004	Patent applications	R&D investment increase innovation rates in large-market OECD countries; a significant relationship between R&D stock and innovation.	20 OECD and 10 Non-OECD countries

Buesa, Heijs and Baumert 2010	Patents registered in European Patents Office (EPO)	Factor variable analysis shows that regional innovation is characterized mainly market size/income level, human capital, productive environment, and level of economic freedom	146 regions of the EU-15 countries
Hsu,Tian and Xua 2014	Patent counts, patent citations, R&D expenses	Industries dependent on external finance and more high-tech intensive exhibit a disproportionally higher innovation level in countries with better developed equity markets. However, development of credit markets appears to discourage innovation in industries dependent on external finance and that is more high-tech intensive.	32 developed and emerging countries
Sandu and Ciocanel 2014	High-technology exports	Positive correlation between total R&D expenditure volume and the level of high-tech exports, with variability between countries. The influence of private R&D expenditure on high-tech exports is stronger than public R&D expenditure.	26 countries (all EU-27 countries, except for Luxembourg), 2006-2010
Ang and Stern 2013	Patents applications by residents	Positive correlation between patenting and R&D investments, knowledge stocks – measured by accumulated patents – and international knowledge spillovers. Negative correlation between patenting and GDP.	26 OECD countries plus China and India for the period 1870-2010

Source: Authors.

A review of existing studies highlights a focus on OECD countries. For instance, in a study of 17 OECD countries, knowledge stock is the main determinant of innovation in four major manufacturing sectors (chemicals, electrical and electronics, and drugs and medicine sectors) and that R&D intensity increases the rate of innovation (Ulku 2005). Also, an increase in the share of researchers in labor force increases innovation only in the large market OECD countries (Ulku 2007).

Fewer studies focus on either the Latin American region, or the Asia and Pacific region. To the best of our knowledge, this is the first study that conducts a comparative analysis of innovation in these regions, and studies in detail the drivers of a broad set of innovation variables across the two regions.

III. DATA

The study uses several input and output indicators of innovation, all of which are sourced from the World Bank's World Development Indicators, the United Nations Educational, Scientific and Cultural Organization (UNESCO), and Atlas of Economic Complexity databases. These include researchers per population, R&D share of GDP, share of researchers in the natural sciences and engineering, patents applications, high technology exports, ECI, scientific publications, and trademark applications.

The Asia and the Pacific (AP) subregions are based on the groupings of the Asian Development Bank (ADB). The Latin American and the Caribbean (LAC henceforth) region is based on the World Bank classification and disaggregated across South America, Central America, and Caribbean. This is the classification used by the Inter-American Development Bank (IADB). Regional averages are GDP-weighted to account for market size and to allow for more meaningful comparisons across regions. Each country is weighted for its participation in the regional GDP for each year, and then an average of the countries is calculated to represent the region.

Table 2: Classifications of Economies

Asia and the Pacific (AP)

Central Asia	East Asia	South Asia	Southeast Asia	The Pacific
Afghanistan	People's Republic of China	Bangladesh	Brunei Darussalam	Fiji
Armenia	Hong Kong, China	Bhutan	Indonesia	Micronesia, Federated. States of
Azerbaijan	Korea, Republic of	India	Cambodia	Kiribati
Georgia	Mongolia	Sri Lanka	Lao PDR	Marshall Islands
Kazakhstan		Maldives	Myanmar	Nauru
Kyrgyz Republic		Nepal	Malaysia	Palau
Tajikistan		Pakistan	Philippines	Papua New Guinea
Turkmenistan			Singapore	Solomon Islands
Uzbekistan			Thailand	Timor-Leste
			Viet Nam	Tonga
				Tuvalu
				Vanuatu
				Samoa

LAO PDR = Lao People's Democratic Republic.
Note: Taipei,China (East Asia) and Cook Islands (The Pacific) are not included because of data unavailability.

Latin America and the Caribbean (LAC)

South America	Central America	Caribbean
Argentina	Belize	Antigua and Barbuda
Bolivia	Costa Rica	Aruba
Brazil	El Salvador	Bahamas, The
Chile	Guatemala	Barbados
Colombia	Honduras	Cayman Islands
Ecuador	Mexico	Cuba
Guyana	Nicaragua	Curacao
Paraguay	Panama	Dominica
Peru		Dominican Republic
Suriname		Grenada
Uruguay		Haiti
Venezuela, RB		Jamaica
		Puerto Rico
		Sint Maarten (Dutch part)
		St. Kitts and Nevis
		St. Lucia
		St. Martin (French part)
		St. Vincent and the Grenadines
		Trinidad and Tobago
		Turks and Caicos Islands
		Virgin Islands (United States)

Source: Authors.

For both AP and LAC, data is constrained for certain years in some countries. For instance, Cook Islands and Taipei,China have no available data for all years and all indicators. Only a handful of countries have data, including Fiji, Papua New Guinea, and Samoa. In LAC, there are clear data gaps for Bolivia and some countries like Chile, Colombia, El Salvador, and Puerto Rico only has data for recent years. A complete description of the data is shared in the appendix.

IV. REGIONAL TRENDS: STYLIZED FACTS

In general, we observe significant inequality and regional heterogeneity in innovation trends, dominated by high-income and upper middle-income countries in both AP and LAC. East Asian economies, particularly the People's Republic of China (PRC), the Republic of Korea (ROK); and Hong Kong, China; and Singapore in Southeast Asia drive most of the innovation indicators. In Latin America and the Caribbean, a diverse set of big economies such as Chile, Brazil, Argentina, Mexico, and Costa Rica influence the regional averages.

Normalized by population and market size, the Asia and Pacific region rank higher than LAC in both innovation input and output indicators. At the same time, innovation seems to be driven more by newly industrialized economies such as the ROK and Singapore. However, in both regions, middle-income countries are on the rise, such as the PRC and Brazil. Additionally, large economies seemingly rank higher in most indicators such as Georgia and Kazaksthan in Central Asia, India and Pakistan in South Asia, Argentina and Brazil in South America, and Costa Rica and Mexico in Central America.

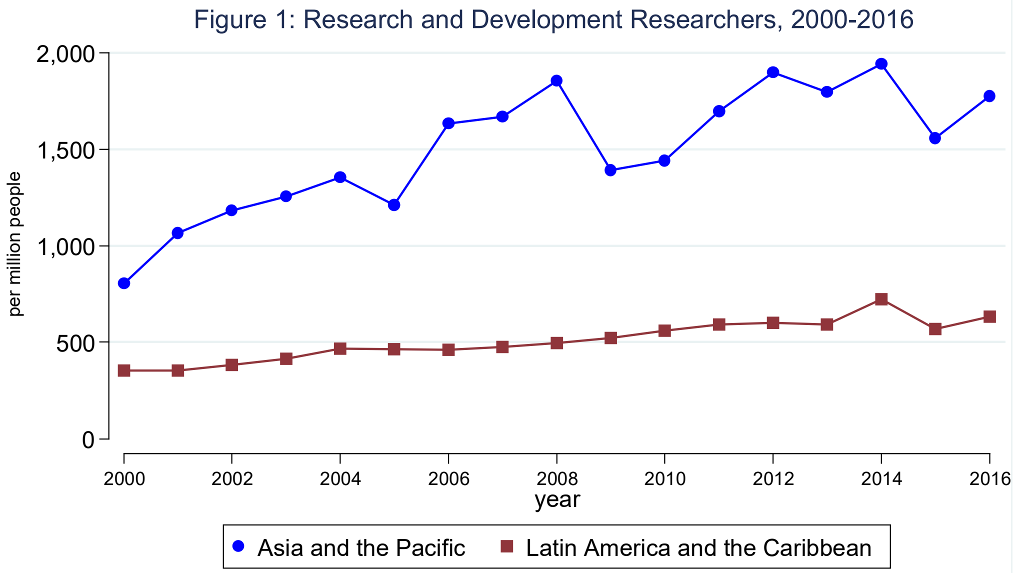
Below we outline the comparative evolution of each of the innovation indicators, focusing on three levels of comparison: regional (AP vs. LAC); intra-regional, and country-level. This distinction is done based on the disaggregation highlighted in Table 2. We further distinguish between innovation inputs and outputs. The input indicators are the human resources such as the number of researchers in Research and Development (R&D), investments, infrastructure, and institutions necessary for innovative activities. On the other hand, output indicators are the result of research and development such as patents, high-technology products, creative outputs like scientific publications and trademarks, as well as quality measures like the ECI.

A. Innovation Inputs

1. Researchers in Research and Development

Researchers engaged in R&D is often characterized as a key innovation input (see, for example, Yueh 2009). Expressed as a proportion of the population, this indicator includes professionals who conduct research and improve or develop concepts, theories, models, techniques, instrumentation, and software of operational methods. The field of R&D covers basic research, applied research, and experimental development, performed and funded by both government and private sectors. To achieve the innovation target in the United Nation's Sustainable Development Goals (SDGs), the UNESCO suggests a ratio of 380 scientists for every million population.[8]

[8] UNESCO Science Report: Towards 2030. SDG Target 9B aims to "*support domestic technology development, research and innovation in developing countries, including by ensuring a conducive policy environment for…industrial diversification and value addition to commodities*".

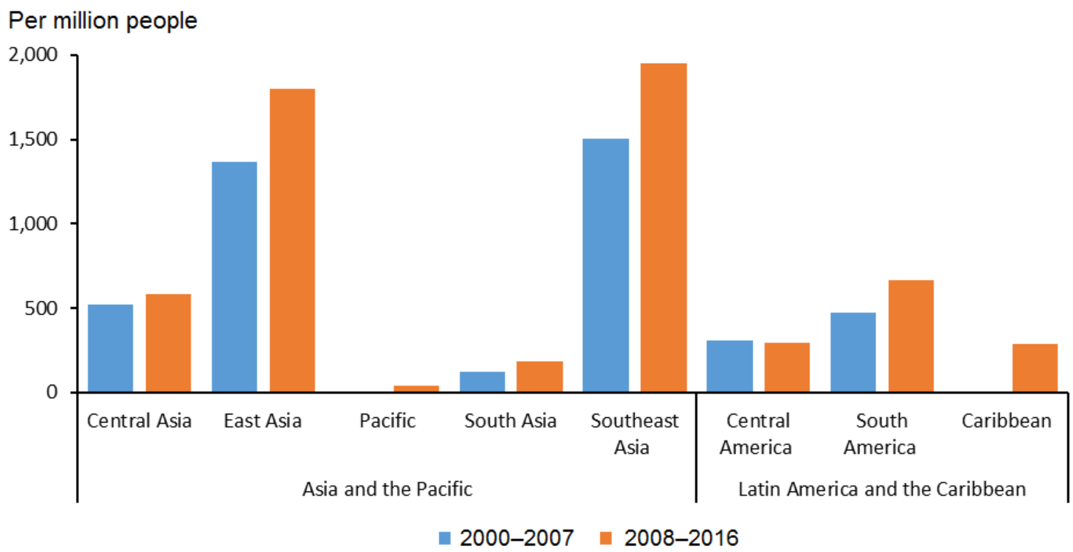


Note: Regional averages are GDP-weighted.
Source: Authors' calculations using World Development Indicators data.

The average number of researchers has grown considerably in developing Asia, steadily increasing from 805 per million people in 2000 to 1,775 in 2016. This was almost three times the average researcher density in Latin America and the Caribbean, which increased from 352 researchers per million to more than 600. This researcher pool in Asia may have contributed to the region's resurgence in innovation, on par with more developed regions.

The growth in Asia have been mostly driven by Southeast Asia and East Asia while in Latin America, these are South and Central America. The uneven but increasing growth in Figure 1 shows the highest figure in 2014. In 2012, researchers in Southeast Asia (4,058) are twice that of East Asia (1,792). Except for South Asia and the Pacific, all the other subregions in Asia meets the UNESCO threshold number of researchers needed for sustained development while only South and Central America meets this requirement in LAC.

Figure 2: Research and Development Researchers, by Subregion



Note: Subregional averages are GDP-weighted.
Source: Authors' calculations using Word Development Indicators data.

Table 3. Top Economies per Subregion, R&D Researchers per Million People

Central Asia		**East Asia**		**South Asia (2015)**		**Southeast Asia**	
Georgia	1,337	Republic of Korea	7,133	Pakistan	294	Singapore, 2014	6,730
Kazakhstan	688	Hong Kong, China	3,405	India	216	Malaysia	2,358
Uzbekistan	506	People's Republic of China	1,206	Sri Lanka	107	Thailand	1,210
						Viet Nam, 2015	672
Average, 2016	683			Average, 2015	219	Philippines, 2013	188
Average, 2000–2016	575	Average, 2016	1,956	Average, 2000-15	166		
		Average, 2000–2016	1,670			Average, 2016	833
						Average, 2000–2016	1,796
Pacific		**South America**		**Central America**		**Caribbean**	
Papua New Guinea	36	Argentina	1,233	Costa Rica	530	Puerto Rico, 2015	321
		Brazil, 2014	881	Mexico, 2013	244		
Average, 2000–2016	36	Uruguay	645	El Salvador	66	Average, 2015	321
		Chile	502	Panama, 2013	39	Average, 2000–2015	290
		Ecuador, 2014	401	Honduras, 2015	23		
		Average, 2016	646	Average, 2016	383		
		Average, 2000–2016	587	Average, 2000–2016	299		

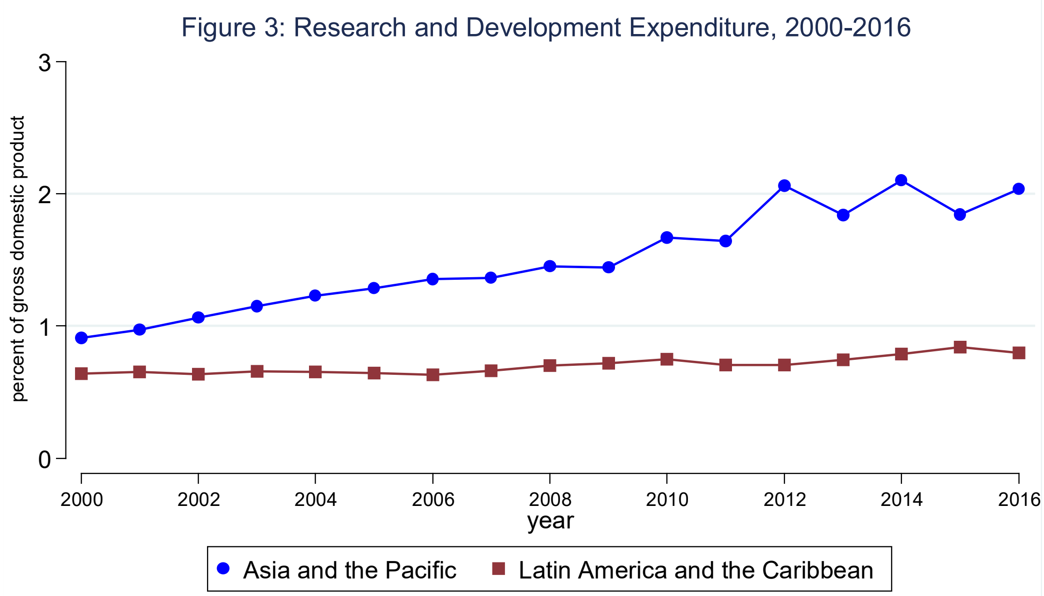
Note: The following table used 2016 data unless otherwise indicated. The 2016 and 2000–2016 figures are subregional averages.
Source: Authors.

In all subregions, most of the top-ranking economies are either high-income or upper middle-income. In the latest year with available data, the ROK has the highest density of researchers in Asia with 7,113 per million people, followed by Singapore; Hong Kong, China; Malaysia; Georgia; Thailand; and the PRC. The ROK has twice the number of R&D researchers than Hong Kong, China and six times that of the PRC and Argentina, the highest-ranked LAC country. Singapore has the highest number of researchers in Southeast Asia, almost three times that of Malaysia. In South Asia, Pakistan has the highest researcher density, followed by India. Countries with the least number of researchers are in the Pacific and Central American economies like Honduras and Panama.

South America leads the Latin America region in the number of researchers. Top countries are Argentina and Brazil, with more than 1,200 and 880 researchers per million citizens each respectively. In Central America, leading countries are Costa Rica and Mexico with 530 and 244 researchers per million inhabitants. In the Caribbean, data is only available for Puerto Rico and the last register of data is for 2015, showing more than 320 researchers per million people. However, while as a region the UNESCO cut-off of 380 scientists per every million population is met, there are large disparities when studying these patterns at a country-level.

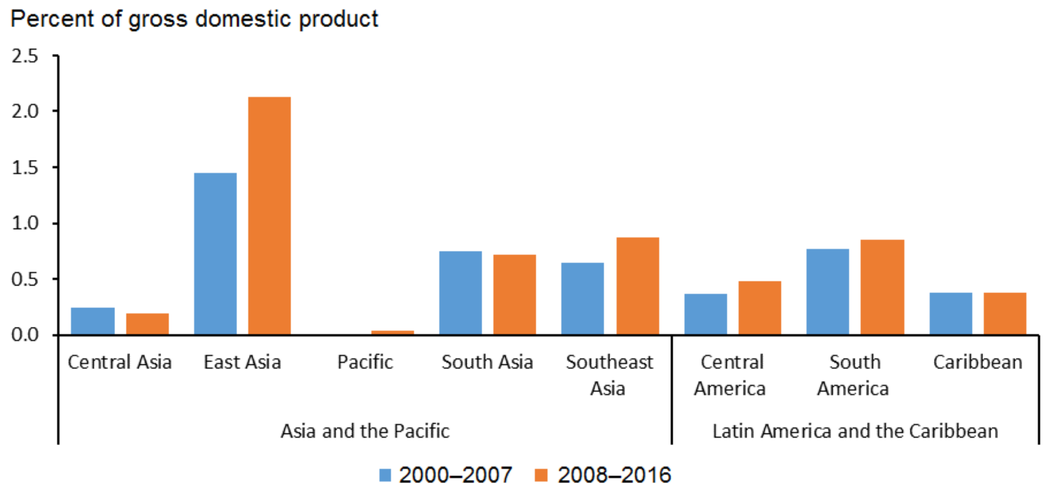
2. Expenditure on Research and Development

R&D intensity or spending on research and development is a major indicator of a country's effort to obtain competitive advantage in science and technology. The gross domestic expenditures on R&D, expressed as percent of GDP, include both capital and current expenditures by business enterprises, government, higher education and private non-profit organizations, in basic research, applied research, and experimental development. For both AP and LAC, this variable is present in more countries for longer periods. The average spending in OECD countries is 2.4% of GDP in 2016 while the 2019 Global Innovation Index shows global average at 1.7% since 2013. The ROK, Singapore, and the PRC in AP and Brazil in LAC are the economies that are closer to the global and OECD average in R&D spending.



Note: Regional averages are GDP-weighted.
Source: Authors' calculations using World Development Indicators data.

Figure 4: Research and Development Expenditure, by Subregion



Note: Subregional averages are GDP-weighted.
Source: Authors' calculations using Word Development Indicators data.

From 2000 to 2016,[9] developing Asia spends approximately 1.6% of total GDP on research and development. Expenditure on R&D more than doubled between 2000 and 2016, from 0.9% to 2.0% of GDP, compared with R&D spending in LAC which ranged from 0.6% to 0.8% in 2016. However, spending in AP has been uneven in recent years though at an increasing pace. This contrasts with the gradual increase in the LAC and which is more evenly spread across the region.

East Asian economies spend more on research and development than any other region in developing Asia, at about 1.9% of GDP on average annually, more than twice than Southeast Asia. South Asia roughly spend 0.7% of its GDP on R&D, Southeast Asia 0.8% and Central Asia about 0.2%, while the Pacific spend a minuscule 0.03%. These subregional figures exhibit similar trends as the human resources available for R&D.

Developing Asia spends more on research and development than LAC and this may have contributed to a higher-level of innovation. In the case of the ROPK, spending almost 4% of domestic output on research and development has enabled it to become one of the most innovative and industrialized economies in the region. The country spends 3% of its GDP annually since 1996. In 2016 alone, the ROK spent an equivalent of 4%–2% of its economic output on research and development. Average spending in the region is much lower if the ROK is not included showing its higher allocation for R&D. Both Singapore and the PRC, allotting about 2% of GDP to R&D, also rank high. In Southeast Asia, Malaysia and Thailand spends the highest shares at 1.4% and 0.8% of GDP, respectively. The R&D intensity in the Central Asian countries has also increased its share ranging from 0.1% to 0.2%, except for Georgia with 0.3%. The remaining economies spend less than 0.1% on R&D.

[9] Our sample ends in 2016 due to data availability for the ROK and the PRC, which comprise a large portion of the region's share.

Table 4: Top Economies per Subregion, Research and Development Expenditure (% of GDP)

Central Asia		East Asia		South Asia (2015)		Southeast Asia	
Georgia	0.30	Republic of Korea	4.23	India	0.62	Singapore	2.22
Armenia	0.23	People's Republic of China	2.11	Pakistan	0.25	Malaysia	1.44
Uzbekistan	0.22	Hong Kong, China	0.79	Sri Lanka	0.11	Thailand	0.78
Azerbaijan	0.21					Viet Nam, 2015	0.44
Kazakhstan	0.14					Indonesia	0.24
Average, 2016	0.18	Average, 2016	2.32	Average, 2016	0.57	Average, 2016	0.78
Average, 2000–2016	0.20	Average, 2000–2016	1.92	Average, 2000–2016	0.73	Average, 2000–2016	0.76
Pacific		**South America**		**Central America**		**Caribbean**	
Papua New Guinea	0.03	Brazil	1.27	Mexico	0.49	Puerto Rico, 2015	0.43
		Argentina	0.53	Costa Rica	0.46	Cuba	0.35
Average	0.03	Ecuador, 2014	0.44	El Salvador	0.15	St. Vincent and the Grenadines, 2002	0.15
		Uruguay	0.41	Nicaragua, 2015	0.11	Trinidad and Tobago	0.11
		Chile	0.36	Panama, 2013	0.06	Jamaica, 2002	0.06
		Average, 2016	0.92	Average, 2016	0.48	Average, 2016	0.29
		Average, 2000–2016	0.82	Average, 2000–2016	0.43	Average, 2000–2016	0.38

Note: The table used 2016 data unless otherwise indicated. The 2016 and 2000–2016 figures are sub- regional averages.
Source: Authors.

By far the country that leads the LAC region in terms of expenditure is Brazil, dedicating nearly 1.3% of the country's GDP to R&D expenditure. Countries that follow Brazil in each regional zone are Argentina with 0.53% in South America, Mexico with 0.49% in Central America, and Puerto Rico with 0.43% in the Caribbean zone. Overall, South America leads in terms of expenditure in R&D as a portion of the countries' GDP in Latin American and Caribbean but is highly driven by Brazil's expenditure.

3. Researchers in Natural Sciences and Engineering

Sourced from the UNESCO database, this indicator measures the number of researchers in the natural sciences and engineering, including in agricultural and medical sciences in full-time equivalent value. The percentage share of researchers to the total number of researchers is used to compare regions and subregions.

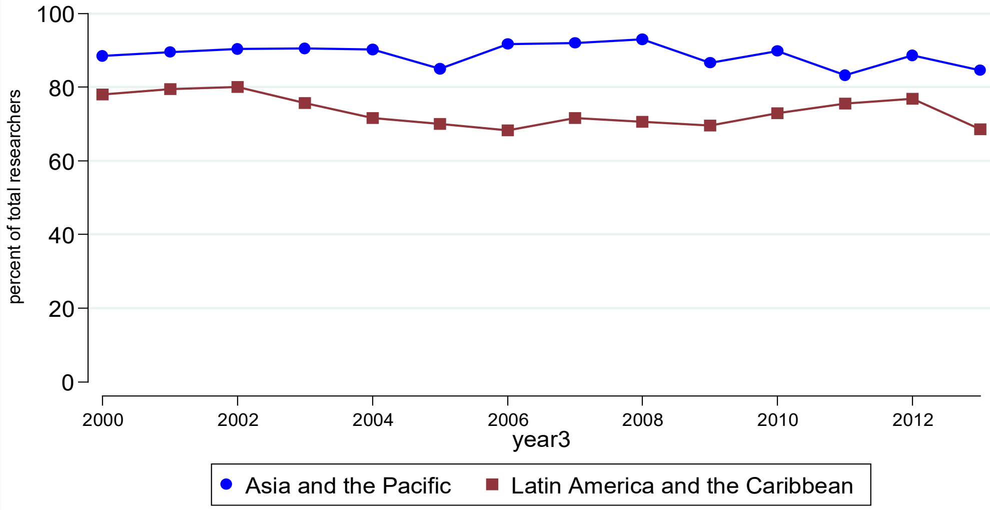
Full-time equivalent (FTE) of R&D personnel is defined as the ratio of working hours spent on R&D divided by the total number of hours conventionally worked in a year by an individual or by a group. One FTE may be thought of as one person-year. Thus, a person who normally spends 30% of his/her time on R&D and the rest on other activities (such as teaching, university administration and student counselling) should be considered as 0.3 FTE. This measure combines two variables: actual involvement in R&D activities and formal engagement based on normative/statutory working hours. FTE is often considered a 'true' measure of the volume of R&D and the main R&D personnel statistic for international comparisons. However, data is based on R&D surveys that affects its availability, especially for R&D-intensive countries such as ROK and the PRC. The limited data is apparent in the latest year as only four countries reported their share of R&D scientists and engineers in Asia and the Pacific, as with the LAC region. This makes it difficult to make regional comparisons.

ROK has no available data while the PRC reported 93% share in 2008. Singapore has the highest number of scientists and engineers in its R&D pool with 95% in 2014 and averaging around that number annually. In Southeast Asia, 82% of researchers in Malaysia are scientists and engineers in 2015 but this fell from 92% in 2002. In Thailand, the share decreased from 44% in 2005 to 26% in 2016. In South Asia, Sri Lanka has the highest share at 87% in 2015. India reported 73% share in 2005. In Pakistan, only 69% are scientists

and engineers from 87% in 2005. Only the Central Asian countries of Uzbekistan and Georgia reported 67% and 58% share in 2016, respectively. Similarly, Papua New Guinea reported 58% share in 2016. With available data, one can fairly say that 80% of researchers are in the natural sciences and engineering in developing Asia. The drastic decrease since 2013 is due more to data unavailability than actual decline in researcher numbers.

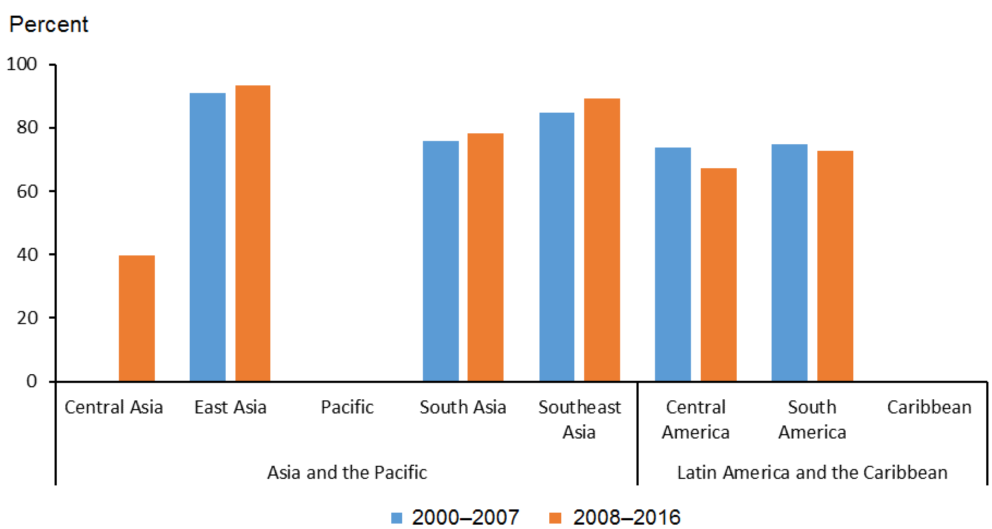
Similarly, in the latest year available, only five countries in the LAC region have data including Chile, Colombia, El Salvador, Paraguay, and Uruguay. Large economies like Argentina, Brazil, and Mexico did not report data on share of scientists and engineers in its R&D personnel.

Figure 5: Researchers in Natural Sciences and Engineering, 2000-2013



Note: Regional averages are GDP-weighted.
Source: Authors' calculations using data from UNESCO Institute of Statistics.

Figure 6: Researchers in Natural Sciences and Engineering, by Subregion



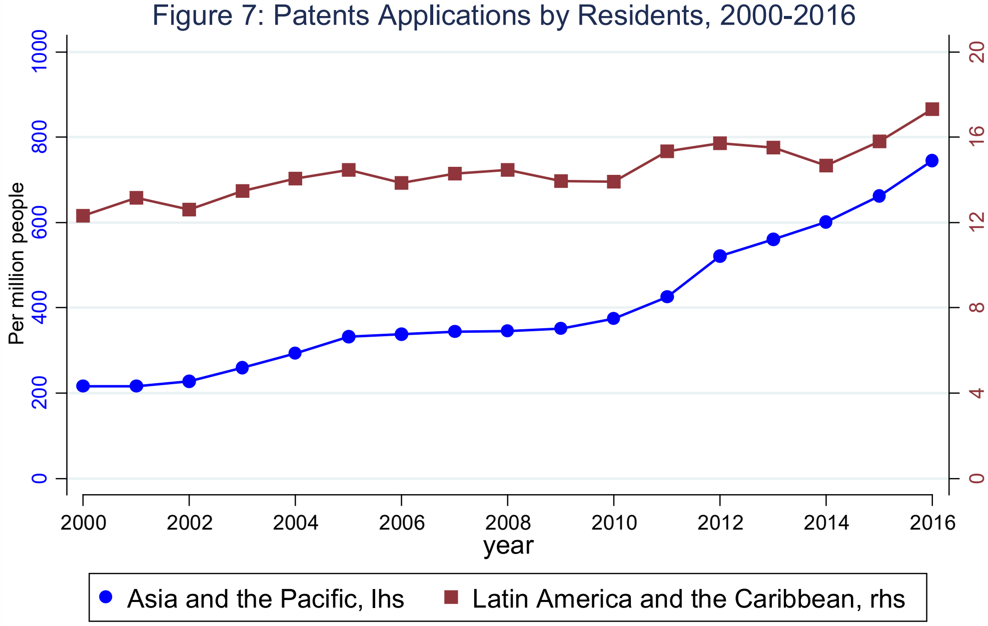
Note: Subregional averages are GDP-weighted.
Source: Authors' calculations using Word Development Indicators data.

B. Innovation Outputs

1. Patents Applications

Patent applications are worldwide patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights to a product or process invention that provides a new way of doing something or offers a new technical solution. A patent provides protection for the invention to the owner of the patent for approximately 20 years. The World bank data only includes applications filed by residents within each country to distinguish those patents made by a country's own residents vis-à-vis those filed by non-residents.

Figure 7: Patents Applications by Residents, 2000-2016



Notes: Regional averages are GDP-weighted. lhs=left hand side, rhs=right hand side.
Source: Authors' calculations using World Development Indicators data.

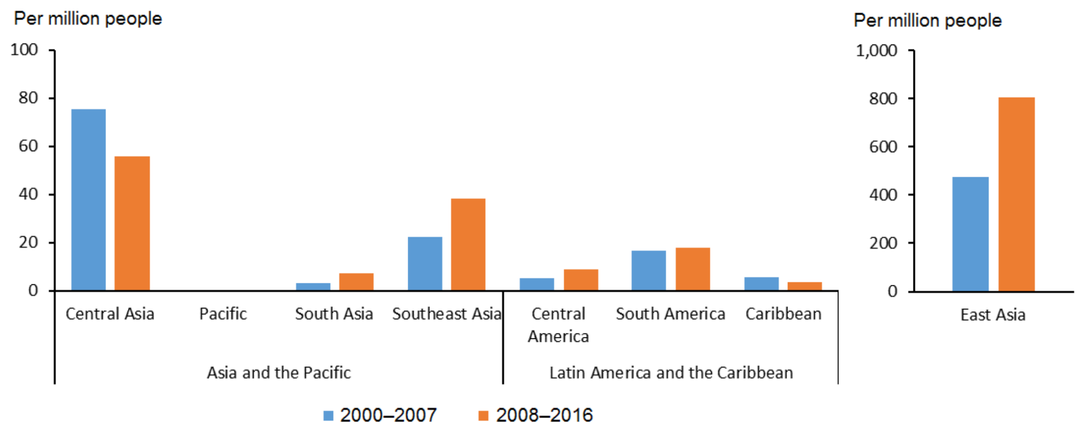
Weighted data from 2000 to 2016 shows the steady increase in patents applications in developing Asia. From 216 patents per million people in 2000, applications have increased to 745 in 2016. In LAC, patent flows have grown almost 50% in the last 20 years, from 12 to almost 18 per million people.

A large share of patents is from East Asian economies. The regional average drastically decreases if the ROK is excluded. In 2016 alone, about 86% of patents filed are from the ROK and the PRC with 3,189 and 374 applications, respectively. Unweighted data shows that about 1.2 million patents were recorded in the PRC in 2016, followed by the ROK with 163,400. This has driven the subregional average from 370 to 1,125 between 2000 and 2016. Patent applications also increased in Southeast Asia, from 19 to 44, and South Asia, from 2 to 9, per million people. There is a marked decrease in Central Asia, from 73 to 38 in 2016.

In the last 10 years, the number of patents per million inhabitants increased from 5 to 10 in Central America. South America went from more than 15 patents per million people in 2010 to more than 20 in 2016. The Caribbean has stagnated around 5 in the number of patents in the first 10 years and went down

from 2011 onwards. When compared with the two other regions, the Caribbean has not grown in terms of patents per million people.

Figure 8: Patent Applications, by Subregion



Note: Subregional averages are GDP-weighted.
Source: Authors' calculations using Word Development Indicators data.

In Southeast Asia, other countries lag Singapore. In South Asia, Sri Lanka has more patent applications (13) in proportion to its population than India (10). Unweighted data in 2016 shows that there were 13,199 applications in India compared with 280 in Sri Lanka. In Central Asia, patent density is higher in Kazakhstan, the largest country in the subregion.

Within South America, leading countries are Brazil with 25 patents per million inhabitants in 2016 followed by Chile with 21 patents per million people in the same year. For Central America, Panama is ranked 1st with 17 patents in 2016 followed by Mexico with 11. Finally, for the Caribbean, Aruba appears leading the subregion, but the data was recorded in 2002. The Bahamas and Jamaica have data for 2016, and they present 8 and 7 patents per million people respectively.

Table 5: Top Economies per Subregion, Patent Applications per Million People

Central Asia		**East Asia**		**South Asia**		**Southeast Asia**	
Kazakhstan	56	Republic of Korea	3,091	Sri Lanka	13	Singapore	287
Armenia	43	People's Republic of China	899	India	10	Malaysia	38
Georgia	26			Bhutan	5	Brunei Darussalam	19
Kyrgyz Republic	22	Hong Kong, China	44	Pakistan	1	Thailand	14
Azerbaijan	15	Mongolia	40	Nepal	1	Viet Nam	9
Average, 2016	38	Average, 2016	1,125	Average, 2016	9	Average, 2016	44
Average, 2000–2016	63	Average, 2000–2016	703	Average, 2000–2016	6	Average, 2000–2016	32
Pacific, 2015		**South America**		**Central America**		**Caribbean**	
Samoa	5	Brazil	25	Panama	17	Aruba, 2002	0.49
Papua New Guinea	<1	Chile	21	Mexico	11	Bahamas, The	0.46
		Argentina	20	Belize	3	Jamaica	0.15
Average, 2016	0.3	Colombia	11	Costa Rica	2	Barbados, 2014	0.11
Average, 2000–2016	0.3	Uruguay, 2015	8	Honduras	1	Cuba	0.06
		Average, 2016	21	Average, 2016	10	Average, 2016	3
		Average, 2000–2016	17	Average, 2000–2016	7	Average, 2000–2016	4

Note: The table used 2016 data unless otherwise indicated. The 2016 and 2000-2016 figures are subregional average.
Source: Authors.

2. High-Technology Exports

High-technology exports are products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery, measured in current US dollar for each year. This variable is accessible for a wide range of countries in the regional macro-zones, and for several years in a row. The data is expressed as percentage of manufactured (merchandise) exports in the WDI database.[10] Often high-technology exports are normalized as share per worker or share in manufactured exports (Tebaldi 2011).

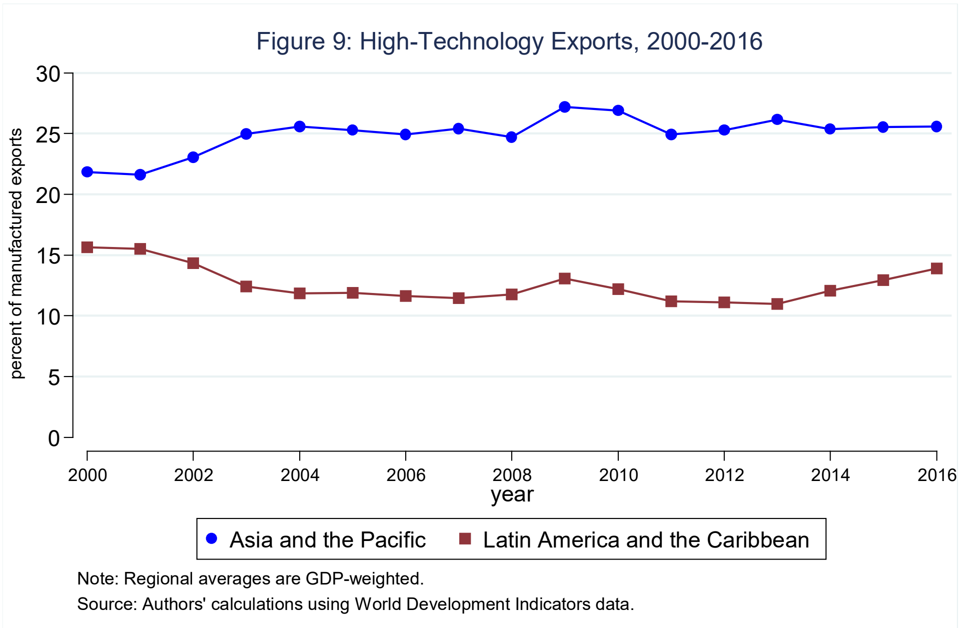
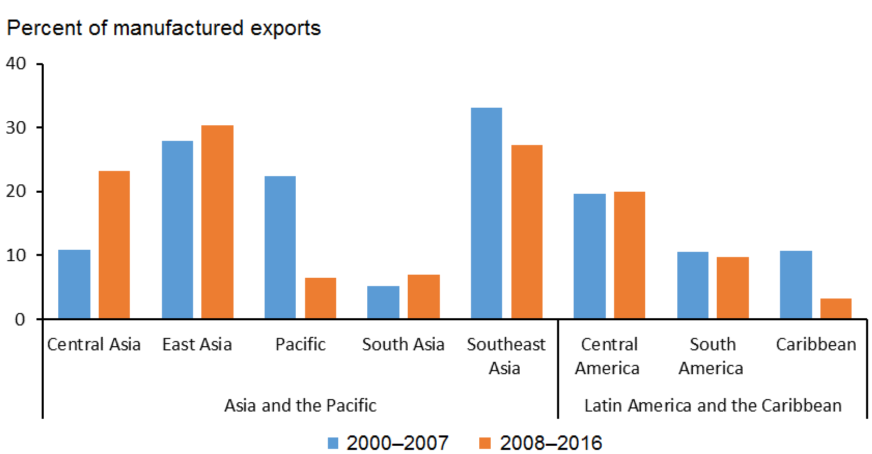


Figure 10: High–Technology Exports, by Subregion



Note: Subregional averages are GDP-weighted.
Source: Authors' calculations using World Development Indicators data.

[10] High-technology exports was also normalized by GDP and the trends and similar patterns were observed. The declining pattern in AP indicates a shift from manufacturing towards services-oriented sectors.

In Asia and Pacific, high-technology exports as share of manufacturing exports has been at the 22%–27% level since 2000. However, it has been declining as share of total manufacturing value added. From about 43% of manufacturing value-added in 2000, high-technology exports were only about 20% in 2016. There is, however, a considerable concentration of exports in some subregions. Exports with high-technology content from Southeast Asia make up a large percentage of the regional share. However, these too are declining. Southeast Asian exports make up about 37% in 2000 but is only 28% by 2016. East Asia hi-tech exports make up about 30% of its manufactured exports in 2016 but this been steady in the last 15 years. Only Central Asia and South Asia has seen increasing share of high-technology exports during the same period.

For Latin America and the Caribbean, Central America has been leading for the last 20 years in high-technology exports as a proportion of its manufacturing output. This is followed by South America and the Caribbean countries. In Central America, the leading country is Costa Rica with $942 million comprising 18% of its manufacturing exports. However, this share has drastically declined from a high base of about 51% in 2000 compared with Mexico which had 22% share in the same year. In terms of value, Mexico had almost $47 billion in exports of high technology in 2016, equal to 15% of manufactured exports. This is similar in South America where Brazil leads the subregion with $9 billion in high-tech exports, equivalent to 13.5% of total manufactured exports but Suriname has a higher ratio of high-tech exports to manufactured exports. In the Caribbean, the share of high-tech exports in St. Kitts and Nevis and Barbados are 29.5% and 24.4% of manufactured exports, respectively. Relying mostly on agricultural products and natural resources, the commodities boom may explain the decline in the region. Economies with higher share of high-technology exports not known for manufacturing export-led growth is also apparent in Southeast Asia.

With a relatively small manufacturing sector, the Philippines leads the subregion with 55% in 2016, followed by Singapore with 52%. However, Singapore exported about $126 billion worth of high-technology products in 2016 compared with $26 billion worth of Philippine exports. Singapore has been the leading exporter of high-technology products in Southeast Asia, but this has decreased from 63% in 2000 to about 52% of manufactured exports in 2016. High-technology exports are its major commodity, comprising a major share of its total manufacturing value added. Most of Singapore's manufactured goods are with high-technology content compared with about a quarter share in the ROK and the PRC. Viet Nam had the biggest improvement, from 11% to 39% in 2016. On the other hand, Malaysia decreased its share of high-technology exports in total manufactured exports from 60% share to only 28% by 2016. The Philippines also declined from a 72% share in 2000. The relocation of production hubs especially high-tech firms from East Asia to Southeast Asia due to labor costs may explain the higher share of high-technology exports in such economies as the Philippines and Viet Nam.

For the last 16 years, exports from the ROK has been consistent at about 30%, with 2016 share at 30.5% of manufacturing exports, equivalent to $118 billion worth of goods. From 19% in 2000, high-technology exports from the PRC has been uneven, increasing to more than 30% until 2007 and peaking at 32.2% by 2010. However, in terms of value, the PRC is still the biggest exporter in the region. It exported $496 billion worth of high-technology products in 2016, from $41 billion in 2000. This shows the East Asia trend of steady exports amidst the shift in manufacturing to services in these economies as well as the effects of trade shocks.

The other developing Asia subregions has either increasing or stable exports share but this has been minuscule compared with the size of its economies. In Central Asia, Kazakhstan increased its share from 1% to 31% from 2000 to 2016. Both the Kyrgyz Republic and Armenia maintained its share, but Georgia

and Azerbaijan have seen a marked decline in exports. Nevertheless, this shows the diversification from natural resources-intensive sectors to high-technology manufacturing in Central Asian economies. In South Asia, India has the highest share followed by Pakistan with Sri Lanka and Nepal still below 1% of manufacturing output. The latter economies still rely on commodities as main exports. The Pacific economies also similarly rely mostly on natural resource exports except for Palau which saw rapid growth from 19% in 2012 to 60% in 2016 with high-technology exports valued at $3 million.

Table 6. Top Economies per Subregion, High-Technology Eexports
(% of manufactured exports)

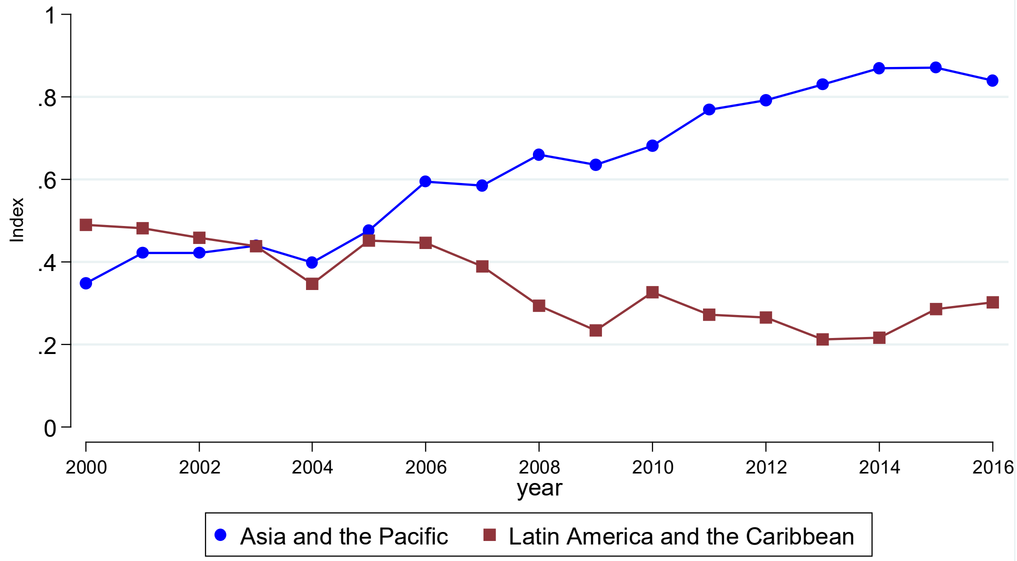
Central Asia		East Asia		South Asia		Southeast Asia	
Kazakhstan	30.7	Republic of Korea	30.5	India	7.7	Philippines	55.1
Kyrgyz Republic	19.7	People's Republic of China	30.3	Pakistan	2.0	Singapore	52.4
Armenia	6.1	Mongolia	16.5	Sri Lanka	0.9	Malaysia	48.9
Georgia	4.6	Hong Kong, China	13.5	Nepal	0.8	Viet Nam	37.8
Azerbaijan	2.7			Maldives	0.03	Lao PDR	33.6
Average, 2016	22.3	Average, 2016	29.9	Average, 2016	6.9	Average, 2016	27.8
Average, 2000–2016	19.1	Average, 2000–2016	29.6	Average, 2000–2016	6.3	Average, 2000–2016	29.4
Pacific		**South America**		**Central America**		**Caribbean**	
Palau	60.5	Suriname	24.1	Mexico	20.8	St. Kitts and Nevis	31.3
Kiribati	6.0	Brazil	14.3	Costa Rica	18.5	Barbados	24.4
Fiji	2.4	Colombia	10.3	Panama	9.2	St. Lucia	5.9
Solomon Islands	1.8	Uruguay	10.0	Guatemala	5.8	Dominican Republic	4.4
Samoa	1.0	Argentina	9.0	El Salvador	5.4	Aruba	3.8
Average, 2016	4.5	Average, 2016	12.1	Average, 2016	19.2	Average, 2016	5.2
Average, 2000–2016	14.5	Average, 2000–2016	10.1	Average, 2000–2016	19.9	Average, 2000–2016	7.0

Lao PDR = Lao People's Democratic Republic.
Note: The table used 2016 data unless otherwise indicated. The 2016 and 2000–2016 figures are subregional averages.
Source: Authors.

3. Economic Complexity Index

The ECI captures the degree of sophistication of the production structure of an economy, sourced from Harvard University's Atlas of Economic Complexity. The index measures the knowledge intensity of an economy by considering the knowledge intensity of the products it exports. A higher value in the ECI means higher "knowledge/R&D intensity" of exports leading to more complex products, and a lower value otherwise. If a country produces only a few goods, that economy is not very complex leading to a lower value in the ECI. If a country produces different goods but can be replicated elsewhere, then it is not complex either.

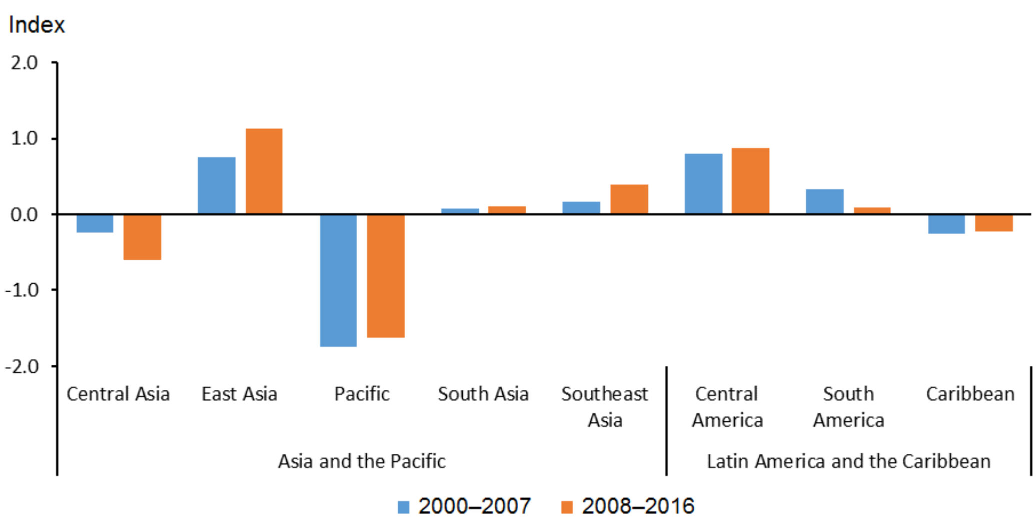
Figure 11: Economic Complexity Index, 2000-2016



Source: Authors' calculations using data from Atlas of Economic Complexity, Harvard University.

The average score in developing Asia is 0.63, showing the improved production structures in the region. However, there is a wide gap between East Asia, Southeast Asia, and other subregions in ECI scores. The regional average is significantly lower if the PRC, the ROK, and Singapore are excluded, with a difference of 0.10 to 0.20 index points. Except for the Pacific, developing Asia subregions has improved in the ECI rankings, signifying the shift to complex and knowledge-intensive industries. From 2000 to 2016, East Asian economies consistently score higher in the index (1.0 on average). Southeast Asia improved its score since 2000, with average score at 0.3. The average score in South Asia and Central Asia are 0.1 and -0.5, respectively. The Pacific region continues to lag in the index.

Figure 12: Economic Complexity Index, by Subregion



Note: Subregional averages are GDP-weighted.
Source: Authors' calculations using data from Atlas of Economic Complexity, Harvard University.

In the region, newly industrialized and export-oriented countries like the ROK and Singapore are ranked higher at 1.9. Bottom-tier countries are those in the Pacific and Central Asia, resource-rich countries that are slowly diversifying to improved production capabilities.

In the last two decades, Central America has been rising in the ECI, from -0.3 in 2000 to almost 0.1 in 2016. In contrast, South America seems to have been declining, from -0.1 in 2000 to -0.4 in 2016. The Caribbean has shown great volatility with ups and downs in this period, but overall, they seem to be a bit better than two decades ago with an ECI of almost -0.2.

Within the leading region of Central America, there are two countries well above the leading country in South America. These countries are Mexico that has an ECI of 1.1 and Panama that has an ECI of 0.6. In South America the leading country has an ECI of 0.3 and it is Brazil, followed by Uruguay and Colombia both with 0.2. In the Caribbean zone, the country with higher ECI is Trinidad and Tobago with 0, and Jamaica with -0.2.

Table 7: Top Countries per Subregion, Economic Complexity Index

Central Asia		**East Asia**		**South Asia**		**Southeast Asia**	
Kyrgyz Republic	0.1	Republic of Korea	1.9	India	0.4	Singapore	1.9
Armenia	0.1	PRC	1.1	Sri Lanka	-0.5	Malaysia	1.0
Kazakhstan	-0.2	Mongolia	-0.7	Pakistan	-0.6	Thailand	0.9
Georgia	-0.3			Bangladesh	-1.0	Philippines	0.6
Uzbekistan	-0.5	Average, 2016	1.2			Viet Nam	-0.1
		Average, 2000–2016	1.0	Average, 2016	0.2		
Average, 2016	-0.4			Average, 2000–2016	0.1	Average, 2016	0.4
Average, 2000–2016	-0.5					Average, 2000–2016	0.3
Pacific		**South America**		**Central America**		**Caribbean**	
Papua New Guinea	-1.8	Brazil	0.3	Mexico	1.1	Trinidad and Tobago	0.0
		Uruguay	0.2	Panama	0.6	Jamaica	-0.2
Average, 2016	-1.8	Colombia	0.2	Costa Rica	0.3	Dominican Republic	-0.2
Average, 2000–2016	-1.7	Argentina	-0.1	El Salvador	0.2	Cuba	-0.6
		Chile	-0.3	Guatemala	-0.3		
						Average, 2016	-0.3
		Average, 2016	0.1	Average, 2016	0.9	Average, 2000–2016	-0.2
		Average, 2000–2016	0.2	Average, 2000–2016	0.8		

PRC = People's Republic of China.
Note: The table used 2016 data unless otherwise indicated. The 2016 and 2000–2016 figures are subregional averages.
Source: Authors.

4. Scientific Publications

Bibliometrics has been in use in previous studies to study innovative activity in the economy. As defined by the World Bank, scientific and technical journal articles refer to the number of scientific and engineering articles published in physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences. Though this indicator may be biased towards highly publicized research, the data in per million population approximates well the intensity of research activity between the public and private sectors, especially the education and industry sectors which might then lead to practical applications and innovations.

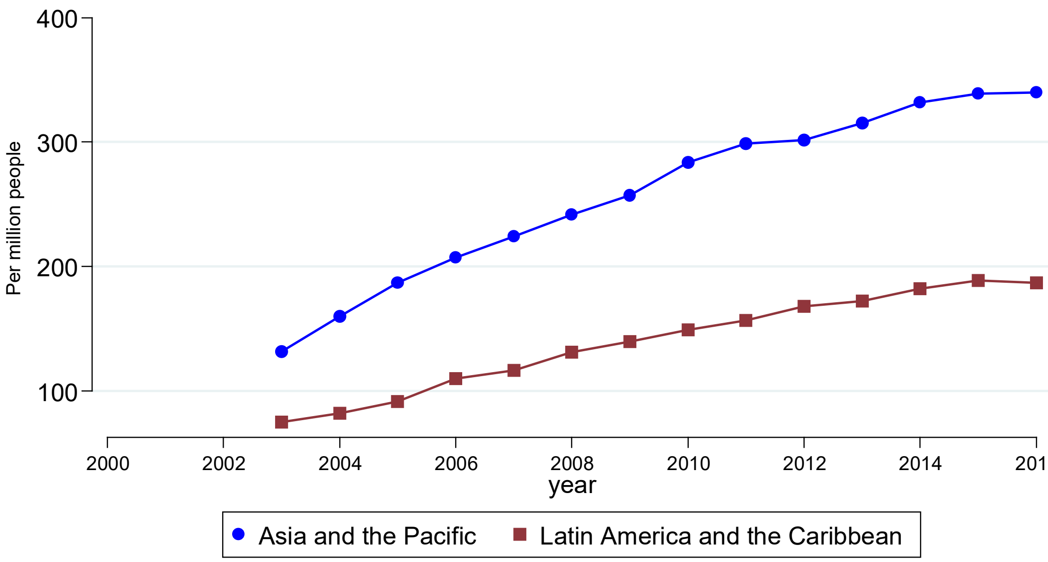
Scientific publications in developing Asia has been steadily increasing since 2003. However, GDP-weighted data shows higher regional averages in East Asia and Southeast Asia at 420 and 356 scientific publications per million people, respectively. As seen in Table 8, the latest year average shows a marked increase from the 13-year averages. All the subregions are increasing its share from 2003 levels, showing intensified

research activities. This is consistent with the other trends in the other innovation indicators such as the number of researchers, R&D expenditure, patent applications, and the ECIdex.

Similarly, there is also an increasing trend observed in Latin America. The latest year average is 227 and 106 per million people in South America and Central America respectively, improving from its 13-year averages. The regional average is driven by the bigger and richer countries such as Chile and Brazil in the former and Mexico and Costa Rica in Central America. On the other hand, the Caribbean has seen a decline from its annual average.

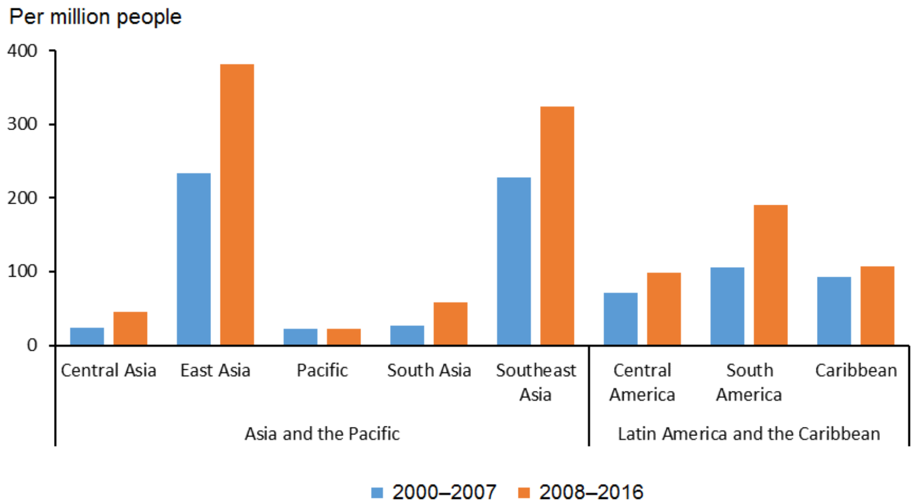
Population-weighted data shows Singapore leads the region in scientific publications with 2,007 per million people, followed by the ROK with 1,231. Though the PRC figure is at 309, unweighted data shows that there are more than 426,165 publications in the country alone in 2016, followed by India with 110,320, the ROK with 63,063, Malaysia with 20,332, and Singapore with 11,254 publications. In Central Asia, Armenia leads the subregion with 177 though unweighted shows Kazakhstan publishes more at 1,564 scientific publications vis-a-vis 521 in Armenia.

Figure 13: Scientific Publications, 2000-2016



Note: Regional averages are GDP-weighted.
Source: Authors' calculations using World Development Indicators data.

Figure 14: Scientific Publications, by Subregion



Note: Subregional averages are GDP-weighted.
Source: Authors' calculations using Word Development Indicators data.

Table 8: Top Countries per Subregion, Scientific Publications per Million People

Central Asia		East Asia		South Asia		Southeast Asia	
Armenia	177	Republic of Korea	1,231	India	83	Singapore	2,007
Georgia	155	PRC	309	Bhutan	55	Malaysia	663
Kazakhstan	88	Mongolia	37	Sri Lanka	49	Brunei Darussalam	557
Azerbaijan	49			Pakistan	45	Thailand	139
Kyrgyz Republic	17	Average, 2016	420	Bangladesh	16	Viet Nam	32
		Average, 2003–2016	347				
Average, 2016	64			Average, 2016	75	Average, 2016	356
Average, 2003–2016	39			Average, 2003–2016	50	Average, 2003–2016	297
Pacific		**South America**		**Central America**		**Caribbean**	
Fiji	178	Chile	370	Mexico	118	St. Kitts and Nevis	403
Palau	175	Brazil	260	Costa Rica	77	Grenada	311
Nauru	54	Uruguay	236	Panama	39	Barbados	169
Vanuatu	49	Argentina	198	Belize	15	Puerto Rico	166
Tuvalu	36	Colombia	127	Nicaragua	6	Trinidad and Tobago	134
Average, 2016	31	Average, 2016	227	Average, 2016	106	Average, 2016	93
Average, 2003–2016	23	Average, 2003–2016	165	Average, 2003–2016	89	Average, 2003–2016	103

PRC = People's Republic of ChIna.
Note: The table used 2016 data unless otherwise indicated. The 2016 and 2000–2016 figures are subregional averages. Source: Authors.

5. Trademark Applications

The literature suggests that trademarks complements patents and are both used to study protection of intellectual property (Blind et al. 2006 and Thomä and Bizer 2013). Unlike patents, recent research used trademark data as proxy to study the commercialization of new innovations. Trademark applications are filed to register a trademark with a national or regional intellectual property (IP) office. It is defined as a distinctive sign which identifies certain goods or services as those produced or provided by a specific

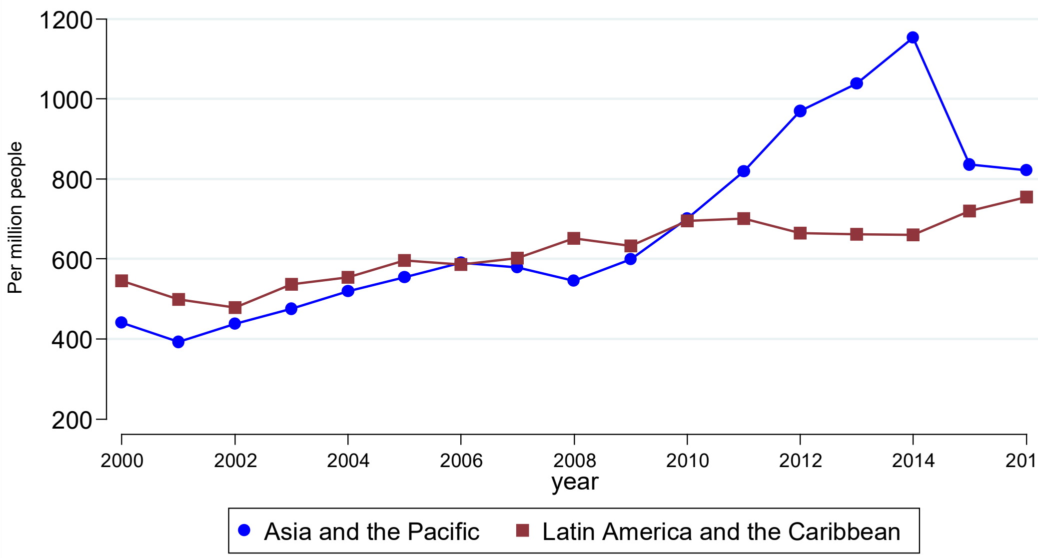
person or enterprise. It provides protection to the owner of the mark by ensuring the exclusive right to use it to identify goods or services, or to authorize another to use it in return for payment. The period of protection varies, but a trademark can be renewed indefinitely beyond the time limit on payment of additional fees.

The data is normalized by population and includes resident and non-resident applications. Many offices in middle- and low-income economies have considerably high numbers of trademark applications compared with other forms of IP, showing the emphasis placed on trademark rights in these markets.

In developing Asia, trademark applications have been steady at more than 900 applications per million population annually. Subregional averages have improved showing more trademarks are filed in the region as new products and services are introduced. East Asian economies such as Hong Kong, China and the ROK, as well as Singapore in Southeast Asia has been driving growth in this indicator. In 2016, Hong Kong, China registered 4,932 trademark applications showing its role as one of the world's main hubs of IP-related services. Similarly, Singapore is also a main center of IP applications. On the other hand, the ROK registered 3,549 applications, which are mostly resident filings.

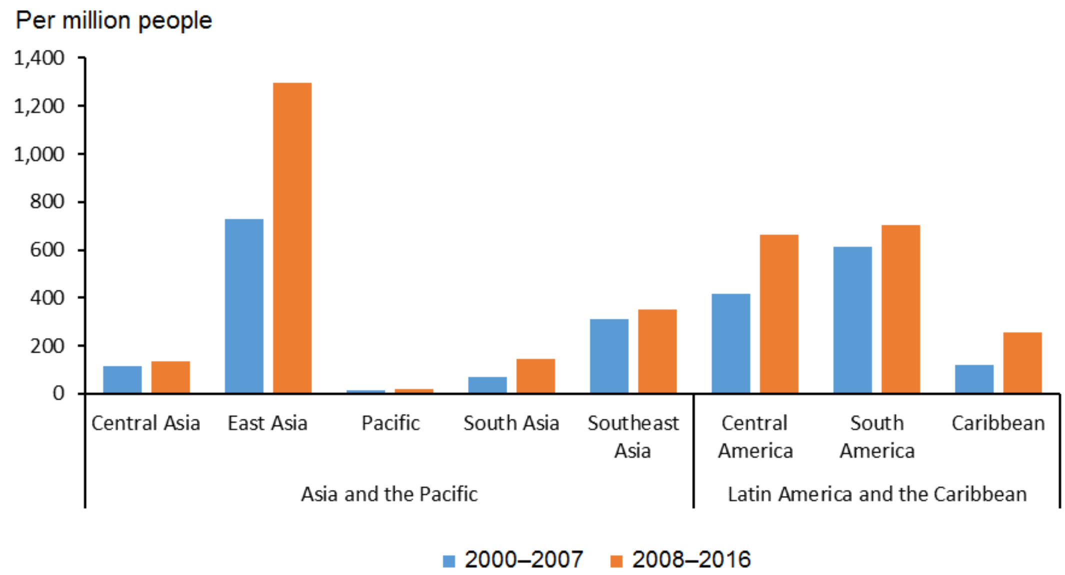
In Latin America and the Caribbean, all the three subregions have seen marked increase in trademark applications since 2000 as the three LAC subregions registered higher or near-comparable with the developing Asia average. Overall, Central America registered higher filings while the Caribbean has more trademark filings than South America.

Figure 15: Trademark Applications, 2000-2016



Note: Regional averages are GDP-weighted.
Source: Authors' calculations using World Development Indicators data.

Figure 16: Trademark Applications, by Subregion



Note: Subregional averages are GDP-weighted.
Source: Authors' calculations using Word Development Indicators data.

Table 9: Top Economies per Subregion, Trademark Applications per Million People

Central Asia		East Asia		South Asia		Southeast Asia	
Armenia	429	Republic of Korea	3,066	Sri Lanka	325	Singapore	1,045
Georgia	397	Hong Kong, China	1,818	India	200	Malaysia	604
Kazakhstan	173	PRC, 2014	1,463	Pakistan	133	Thailand	482
Azerbaijan	106	Mongolia	372	Nepal	118	Vietnam	373
Uzbekistan	84			Bangladesh	54	Indonesia	186
		Average, 2016	2,833				
Average, 2016	158	Average, 2000–2016	1,089	Average, 2016	189	Average, 2016	402
Average, 2000–2016	128			Average, 2000–2016	119	Average, 2000–2016	337
Pacific		**South America**		**Central America**		**Caribbean**	
Samoa	113	Chile	1,370	Costa Rica	1,387	Bahamas, The	1,125
Papua New Guinea	13	Argentina	1,279	Panama	898	Barbados	707
		Brazil	669	Mexico	801	Dominican Republic	635
Average, 2016	17	Peru	565	El Salvador	570	Jamaica	397
Average, 2000–2016	17	Ecuador	561	Belize	266	Trinidad and Tobago	296
		Average, 2016	753	Average, 2016	811	Average, 2016	390
		Average, 2000–2016	668	Average, 2000–2016	556	Average, 2000–2016	212

PRC = People's Republic of China.
Note: The table used 2016 data unless otherwise indicated. The 2016 and 2000–2016 figures are subregional averages.
Source: Authors.

V. EMPIRICAL ANALYSIS: DATA AND METHODOLOGY

We further investigate the determinants of innovation in Asia and the Pacific and Latin America and the Caribbean. In line with the literature, we use patents application as proxy for innovation.[11] The estimated equation takes the following functional form:[12]

$$\text{Innov}_{it} = \alpha\, RD_{I,t-2} + X'_{it}\,\beta + \varepsilon_{it} \qquad (1)$$

where *Innov* refers to flows of innovation as measured by the patent flows of country *i* in year *t*, *RD* is the stock of R&D expenditure (lagged) defined as total annual expenditure on R&D in each country, the main explanatory variable, to account for knowledge stock and human capital in the R&D sector, *X* is the vector of time-varying country-level control variables, and the disturbance term ε_{it}, including country and fixed effects. All variables are in natural logs. The estimation used fixed-effects regression[13] with robust standard errors on an (unbalanced) panel data of 22 AP and 20 LAC economies from 2000-2016.

Country and year dummies have been included to control for the time trend and idiosyncratic shocks as is standard in the literature. ADB and Latin America and the Caribbean regional groups described earlier are used.[14] We also present results based on various combinations of region-country groups to provide a granular understanding of the drivers of innovation across regions. Robust standard errors are clustered at the country level.

Table 10: Regression Variables

Dependent	Independent
1. Patent flows (number of patent applications by residents, World Development Indicators)	1. Research and development expenditure 2. Secondary school enrollment 3. Openness (exports plus imports as a share of GDP) 4. Import of manufactured goods, share of total trade in manufactured goods 5. Total trade with the United States, share of GDP (IMF Direction of Trade Statistics) 6. Financial development index (IMF) 7. Percent of population with access to electricity, proxy for infrastructure access/availability 8. Institutional quality/good governance rating, Worldwide Governance Indicators

GDP = gross domestic product, IMF = International Monetary Fund.
Note: Patent flows are normalized by population. All variables are in natural logs except for the financial development index and institutional quality.
Source: Authors.

Table 10 describes the dependent and independent variables used in this part of the paper. For the two dependent variables, all independent variables are used in equation 1. A brief description of these variables used as controls and their motivation follows.

---

[11] The study also tried other variables such as ECI as additional proxy for innovation. However, the actual specification of the ideas production function might be different for each case. For example, the ECI captures innovations much closer to the market than patents or scientific publications. It is highly likely that some relevant explanatory variable we might be omitting in some specification (which is not captured by the fixed effect because it could vary over time).

[12] This innovation function is adapted from Ulku (2004), using a log linearized version.

[13] The fixed-effects model is validated using the Hausman test.

[14] ADB/developing Asia regions are Central Asia, East Asia, South Asia, Southeast Asia, and the Pacific. LAC includes South America, Central America, and the Caribbean.

The stock of research and development expenditure is used to proxy for knowledge accumulation over time (knowledge stock) as well as the human capital in the R&D sector. To construct R&D capital stocks, this study uses 20% value of depreciation as in Ulku (2004) since recent studies find that depreciation rate may be higher than that traditionally assumed 15% and vary across industries. The patents applications data (patent flows) only includes those filed by residents through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention. It is used instead of patents granted due to considerable lag from application to the year it is granted. Its widespread use in innovation research is due to being readily available at longer time series.

The R&D data measures factors in the ideas production process while patents quantify the output of the process. The patent flows, R&D stock, and alternative dependent variables have been normalized either by population or GDP to control for the size of the economy.[15] This approach is consistent with Ulku 2004. Most studies and empirical evidence suggest that patents provide a reliable measure of innovative activity (Acs et al. 2002). It is an important feature of innovation as it protects intellectual property of inventors for developing new products or process. Bloom, Van Reenen, and Williams (2019) further show that patent citations can be a measurable indicator of knowledge spillovers as firms benefit from existing patents to improve existing products or services.

Previous studies used input measures such as R&D spending and output measures like patents. These indicators do not capture all aspects of innovation, so the additional measures are meant as supplements. While a variable like high-technology export is used in a few studies, the ECI—which is available in a comparative way for a large set of countries and it is more comprehensive than high-technology exports—is used in a select study to measure product complexity. Though scientific and journal publications may be biased towards product innovations and that large-firm innovations are more likely to be reported, this measure is nonetheless considered a literature-based innovation output. Trademark applications is also included as it indicates new products and services are being commercialized (IDB 2010). These are complementary indicators to the more usual measures of innovative activity such as patents and R&D spending.

Secondary school enrollments are included to capture the effect of overall human capital or education level of a country in its innovation level. It measures the intensity of human capital investment. A higher level of education share provides a base of highly skilled personnel from which firms and other institutions can draw upon for R&D activities (Stern et al. 2000). The lagged value proxies for higher education capacity needed for innovation-related activities. Gaps in the series are interpolated by averaging data in the preceding and succeeding years.

Other control variables include trade, imports of manufactured goods as share of total trade in manufactured goods, share of US trade in each country's GDP, financial development index, and Worldwide Governance Indicators good governance score. Various studies have documented the role of trade in technology flows and innovation across countries. Trade openness captures the liberalization of the economy to outside trade and the imports of manufactured goods account for the "international technology spillover effect" that may increase developing countries' innovative capacity. Since most patent applications worldwide are also filed with the US Patent Office, the share of US trade controls for the effect of the economic alliance with the world's largest economy.

[15] The variables are normalized to approximate the measures used in the stylized facts.

The International Monetary Fund financial development index measures how developed financial institutions and markets are in terms of depth (size and liquidity), access (ability of individuals and companies to access financial services), and efficiency (ability of institutions to provide financial services at low cost and with sustainable revenues and the level of activity of financial markets). A highly developed financial system has been shown to assist small innovative firms access funding from venture capital investors (Morck and Yeung 2001). In most cases however, evidence shows that financial constraints or "funding gaps" can hold back innovative activities due to the high costs of R&D capital (Hall and Lerner 2010, Kerr and Nanda 2014).

The good governance variable is a normalized score using the index scores from the World Bank's Worldwide Governance Indicators to measure institutional quality. The score (1-6) is calculated from the normalized summation of the six dimensions of governance; voice and accountability, political stability and lack of violence, government effectiveness, regulatory quality, rule of law, and control of corruption (ADB 2018). The scores range from 1 (worst) to 6 (best).

VI. ESTIMATION RESULTS

We describe our results for the dependent variable in the regression specification described in equation 1. In each case, we describe the determinants and drivers of innovation at a regional level and provide an analysis of the comparative trends.[16] The regression tables are relegated to the appendix.

The results suggest that patent flows are positively related to both human capital and investment in the R&D sectors in Asia and the Pacific. According to our results, a 1% increase in per capita R&D investment increases innovation by 0.2% in developing Asia. The coefficient is only slightly lower if a large economy like the PRC is excluded, underscoring the higher innovation level not only in large-market economies but overall as well, extending the findings of Ulku 2004.

Interestingly, the results for R&D stock is negative and statistically significant in the LAC region lending support to previous findings in that the effect of R&D investments on innovation and productivity in Latin America are mixed (Crespi and Zuniga 2010). Accordingly, higher R&D investment in Latin American firms does not lead to higher propensity to innovate, especially in Chile and Mexico (Alvarez et. al 2010, Perez et. al. 2005). These studies show that since firms in these countries are far from the technology frontier, incentives to invest in R&D are weak or absent, investment costs are expensive, and it takes time to realize the effects of such investments.[17]

Secondary school enrollment is a significant driver of patent flows in the Asia and Pacific region but only statistically significant when Brazil is included in the sample for the LAC region. In general, the findings highlight that the importance of human capital for national innovative capacity (Stern et al. 2000, Ulku 2004) and that education plays a key role in country-level innovation (Raghupati and Raghupati 2017).

[16] We also disaggregate the regional regressions into income levels. The results from using income levels are available upon request.

[17] Another factor driving these results could be because of non-linear effects: a minimum level of investment in R&D might be needed to start showing any effect and a typical LAC country is below the threshold. The average spending in OECD is 2.25% of GDP while the latest Global Innovation Index shows global average at 1.7% since 2013. Existing studies report that Latin America and the Caribbean lags other world regions in R&D measures (IDB 2010). A complementary factor might be the degree of orientation of the R&D. It is agreed that R&D goals in Latin America are mostly biased towards basic or social oriented research which not closely connected with market demands.

The coefficient on import share of manufactured goods is not significant in both regions. On the other hand, the coefficient on trade with the US as a share of GDP is statistically significant only in the Asia and Pacific region excluding the PRC.[18] The result may reflect the spillover effect resulting from trade with the US on innovation efforts. Most countries in the Asian region have a high volume of trade with the US and the main source of technological know-how for newly industrialized economies in the region. Surprisingly, this relationship is not statistically significant for the LAC region.

Financial development is not significant in Asia and the Pacific but is positive and significant in the LAC region. This may reflect the fact that access to financial institutions has expanded notably in Latin America in the past decade and compares favorably with other emerging market regions (Heng et al. 2016). Economies in the Asia and Pacific region may not have the required financial institutions and financial markets to support sophisticated export industries.

Provision of infrastructure is positive and significant in the Asia and Pacific region but not in Latin America and the Caribbean. Necessary and resilient infrastructure such as roads, electrical power, water, and information and communication technology complements innovative efforts and the region critical infrastructure investments in recent years in the former region. The findings support the fact that sustained growth needs support from resilient infrastructure (United Nations 2016).

VII. CONCLUSION

In this paper, we analyze and compare innovation trends and determinants of innovation in AP and LAC, two largely middle-income regions. At middle income, innovation holds the key to productivity growth which assumes a larger role in economic growth. The stylized facts suggest that AP invests more in innovative activities and produces more innovative outputs than LAC. This may have contributed to AP's superior growth performance relative to LAC in recent decades. This is an interesting topic for future research.

The regional innovation aggregates mask a great deal of heterogeneity across countries. In AP, innovation is led by PRC and high-income economies such as Korea. These economies have rapidly closed innovation gaps with advanced economies, but the rest of the region lags behind. By the same token, LAC innovation is dominated by high-income economies and large economies. Therefore, while AP is outperforming LAC in innovation, there are many economies in both regions which have a lot of catching up to do.

More in-depth analysis of the determinants of innovation, measured by patent flows, based on panel regressions yield some interesting results. In particular, the determinants seem to differ between the two regions. R&D has a positive and significant effect on innovation in AP, but not in LAC. Furthermore, infrastructure access has a significant impact only in AP whereas financial development affects innovation only in LAC. The only variable which has a positive effect on innovation in both regions is education, although the effect is more significant in AP.

The last result points to the importance of human capital in innovation. This is hardly surprising given that innovation is fundamentally a human endeavor based on human ingenuity. The education systems of both

[18] This is positive and significant in high-income economies, including the ROK and Singapore.

regions must strive to turn out a large pool of potential innovators – i.e. individuals who have strong basic literacy and numeracy skills and can think outside the box. While the lack of a positive link between R&D and patents in LAC may seem surprising, the region files only a miniscule number of patents compared to AP. This suggests that patents may be a relatively minor form of intellectual property in the region.

Overall, our analysis indicates that LAC innovates noticeably less than AP and the determinants of innovation may differ across the two regions. While economists often point to macroeconomic stability and export-oriented growth strategy to explain AP's superior economic performance vis-à-vis LAC in recent decades, our analysis indicates that greater innovativeness may also be a contributing factor. However, there is also plenty of scope for Asian countries besides PRC and NIEs to innovate more to sustain their economic growth.

Empirical results show more obvious results using the patents variable to measure innovation, consistent with most macro-level studies. R&D is a critical determinant of patenting in AP while not a critical determinant in LAC. These seems that while R&D has been a factor for pushing the technological frontier in AP, it has been a non-factor in LAC.

The results also reflect a need to strengthen domestic innovation. Foreign technological innovation is only beneficial if it complements existing indigenous efforts. Adapting foreign technology in domestic industries depends on parallel indigenous innovation efforts and the presence of modern institutional and governance structures and conducive innovation systems (Fu et al. 2011). Even though there is strong technology spillover in Latin America and the Caribbean, importing foreign technology did not translate to increased domestic innovation. This might suggest the low diffusion of R&D knowledge and absorptive capacity of Latin American firms compared to Asian firms. Strong R&D sectors in developing Asia allowed the region to increase its innovation by using local technologies. This supports the premise of R&D growth models that innovation is created in the R&D sectors and endogenously created.

REFERENCES

Acs, Zoltan, Lu Anselin, and Attila Varga. 2002. Patents and innovation counts as measures of regional production of new knowledge. *Research Policy,* 31:7, pp. 1069–1085.

ADB. 2017. Asian Development Outlook 2017 Transcending the Middle-Income Challenge. Asian Development Bank.

Aghion, Philippe and Peter Howitt. 1992. A Model of Growth through Creative Destruction. *Econometrica*, 60:2, pp. 323–351.

Boudreaux, Christopher John. 2017. Institutional Quality and Innovation: Some Cross-Country Evidence. *Journal of Entrepreneurship and Public Policy*. 6:1, pp. 26–40.

Bloom, Nicholas, John Van Reenen, and Heidi Williams. 2019. A Toolkit of Policies to Promote Innovation. *CEP Discussion Paper No. 1634*. July. Center for Economic Performance. London: The London School of Economics and Political Science.

Brahmbhatt, Milan and Albert Hu. 2010. Ideas and Innovation in East Asia. *The World Bank Research Observer*. 25:2 (August), pp. 177–207.

Crespi, Gustavo and Pluvial Zuñiga. 2010. Innovation and Productivity: Evidence from Six Latin American Countries. *IDB Working Paper Series*. 218.

Fieler, Ana Cecília, Marcela Eslava, and Daniel Yi Xu. 2018. Trade, Quality Upgrading, and Input Linkages: Theory and Evidence from Colombia. *American Economic Review.* 108:1, January.

Fu, Xiaolan, Luc Soete, and Carlo Pietrobelli. 2011. The Role of Foreign Technology and Indigenous Innovation in the Emerging Economies: Technological Change and Catching-Up. *World Development,* 39(7): pp 1204–1212.

Hall, Bronwyn and Josh Lerner. 2010. The Financing of R&D and Innovation. *MERIT Working Paper No. 12*. United Nations University - Maastricht Economic and Social Research Institute on Innovation and Technology (MERIT). https://www.merit.unu.edu/publications/wppdf/2010/wp2010-012.pdf

Hsu, Po-Hsuan, Xuan Tian, and Yan Xu. Financial development and innovation: Cross-country evidence. *Journal of Financial Economics* 112, no. 1 (2014): pp. 116–135.

Inter-American Development Bank. 2010. *Science, Technology, and Innovation in Latin America and the Caribbean: A Statistical Compendium of Indicators*. Washington, D.C.

Khanh, Lan Chu. 2019. *The Effect of Financial Development on Economic Sophistication: Evidence from Panel Data*. http://dx.doi.org/10.2139/ssrn.3352387.

Kortum, Samuel. 1997. Research, Patenting, and Technological Change. *Econometrica* 65:6, pp. 1389–1419.

Law, Siong Hook, Weng Chang Lee, and Nirvikar Singh. 2018. Revisiting the finance-innovation nexus: Evidence from a non-linear approach. *Journal of Innovation & Knowledge*. 3:3, pp. 143–153.

Liu, Chengliang and Qingbin Guo. 2019. Technology Spillover Effect in China: The Spatiotemporal Evolution and Its Drivers, *Sustainability*, MDPI Open Access Journal, 11:6, pp. 1–14 (March).

Morck, Randall and Bernard Yin Yeung. 2001. The Economic Determinants of Innovation. Productivity in Canada. Andrew Sharpe & Someshwar Rao, eds. University of Calgary Press; *University of Alberta School of Business Research Paper* No. 2013-645. https://ssrn.com/abstract=2277064.

Norris, Era Dabla, Erasmus Kersting, and Geneviève Verdier. 2010. Firm Productivity, Innovation, and Financial Development. *IMF Working Paper WP/10/49*. {City}: International Monetary Fund.

Raghupati, Viju and Wullianallur Raghupathi. 2017. Innovation at Country-Level: Association between Economic Development and Patents. *Journal of Innovation and Entrepreneurship*. 6:4.

Romer, Paul. 1990. Endogenous Technological Change. *Journal of Political Economy,* 98:5, pp. 71–102.

Stern, Scott, Michael Porter, and Jeffrey Furman. 2000. The Determinants of National Innovative Capacity. *NBER Working Paper* No. 7876, September. {City}: The National Bureau of Economic Research.

Tebaldi, Edinaldo. 2011. The Determinants of High-Technology Exports: A Panel Data Analysis. *Atlantic Economic Journal*. 39:4, pp. 343–353.

Ulku, Hulya. 2004. R&D, Innovation, and Economic Growth: An Empirical Analysis. *IMF Working Paper No. 04/185*. Washington, DC: International Monetary Fund.

Ulku, Hulya. 2005. R&D, Innovation, and Growth: Evidence from Four Manufacturing sectors in OECD Countries. *Oxford Economic Papers*, 59:3, pp. 513–535.

Ulku, Hulya. 2007. R&D, Innovation and Output: Evidence from OECD and Non-OECD Countries. *Applied Economics.* 39:3, pp. 291–307.

United Nations. 2016. Industry, Innovation, and Infrastructure: Why it Matters? http://www.un.org/sustainabledevelopment.

Yueh, Linda. 2009. Patent laws and innovation in China. *International Review of Law and Economics*. 29:4, pp. 304–313.

APPENDIX: EMPIRICAL RESULTS

Patent flows	Developing Asia	Developing Asia excl. PRC	Developing Asia excl. NIEs	Latin America and the Caribbean (LAC)	LAC excl. Brazil
Research and development stock	0.215**	0.174**	0.176**	-0.181**	-0.172*
	(0.101)	(0.079)	(0.082)	(0.084)	(0.091)
Secondary school enrollment	2.001***	1.096**	2.184***	1.056*	0.963
	(0.682)	(0.446)	(0.675)	(0.523)	(0.765)
Trade Openness	-0.305	-0.070	-0.470	-0.062	-0.081
	(0.353)	(0.287)	(0.379)	(0.637)	(0.669)
Import of manufactured goods	-0.754	0.151	-0.696	-1.257	-1.137
	(0.685)	(0.524)	(0.770)	(0.921)	(1.123)
United States trade, % of gross domestic product	0.127	0.173**	0.099	-0.184	-0.197
	(0.079)	(0.078)	(0.077)	(0.370)	(0.356)
Financial development, index	0.978	-0.530	1.150	7.435***	8.040**
	(1.409)	(0.728)	(1.406)	(2.005)	(2.955)
Infrastructure access	1.883**	2.672***	2.149**	-3.239	-3.226
	(0.722)	(0.544)	(0.780)	(2.261)	(2.246)
Governance index, Worldwide Governance Indicators	0.047	0.080	-0.002	0.638	0.571
	(0.307)	(0.211)	(0.323)	(0.379)	(0.456)
Observations	264	247	230	193	177
R-squared	0.562	0.521	0.563	0.278	0.281
Number of countries	20	19	18	18	17
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

PRC = People's Republic of China, NIE = Newly industrializing economies, FE = fixed effects.
Note: NIE include the Republic of Korea and Singapore.
Source: Authors.