

Knowledge, Knowledge... Knowledge for My Economy[†]

By RICHARD B. FREEMAN^{*}

The creation of S&T knowledge and development of S&T- based innovation has spread worldwide from traditionally advanced countries to traditionally developing countries, often under the direction of governments. Korea is an exemplar in this new locus. Korea's burst in Science and Technology during the last three decades has made Korea a substantive player in the global production of S&T knowledge and its application to business. Although Korea still trails the US and other top countries in the quality of research, it has leaped from its 1980s standing as bit player in the knowledge economy to being among the leaders in the early 21st Century. This paper shows that Korea's advance benefited from its active participation in the global market in higher education, in international research collaborations, and its close ties to the U.S. Korea's experience offers lessons for other countries who seek to advance by becoming knowledge economies. Korea proves that a developing country can gain comparative advantage in knowledge production and use; that government policy can stimulate such a development; and that openness to the world of higher education and research is the best way to move forward and overcome the middle income trap.

Key Word: Korea, Science and Technology, Education, R&D,
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* Professor, Harvard University (Email: rbfreeman@gmail.com)

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The creation and application of scientific and technological (S&T) knowledge is arguably the “one ring that rules them all” in modern economies (Freeman 2014). It is hard to imagine anything contributing more to the trend rise in living standards and longer and healthier lives than advances in S&T knowledge and its application to the production of goods and services. Once viewed as the exclusive province of advanced countries, the creation of S&T knowledge and the development of S&T-based business innovations have spread to developing countries, often under the direction of governments who view S&T as the road to economic growth and prosperity.

Korea is an exemplar of the new locus of knowledge creation and government efforts to accelerate the growth of the knowledge economy. In the 1950s, Korea was one of the world’s most impoverished countries. It had few scientists and engineers and virtually no presence in science or in the high value added industries that are the core of modern economies. Recovering from the Korean War, the government set up agencies to spur science and technology – the Korea Institute of Science and Technology (set up in 1966), the Ministry of Science and Technology (1967), and the Korea Advanced Institute of Science and Technology (1971). But R&D spending, research personnel, and contributions to knowledge through scientific papers remained negligible until the 1980s, when Korean investments in higher education and knowledge creation increased rapidly and began to pay off in terms of sizable supplies of scientists and engineers and research outcomes. From the 1980s through the 2010s, enrollments in university education grew in Korea to such an extent that the country became a world leader in the share of young persons with bachelor’s, master’s, and Ph.D. degrees. The government established research institutes to undertake basic and applied research in diverse areas, including a center on Kimchi, and experimented with new policies and laws to move research findings from labs to commercial innovations. By the mid-2010s, Korea had the highest R&D-to-GDP ratio in the world, was a major producer of scientific papers and patents relative to its population, and was an exporter of high-tech manufacturing goods. Korean firms such as Samsung were among the top business innovators in the global economy.

How did Korea become a knowledge economy? How important were international collaborations, particularly with the U.S., in Korea’s spurt in the areas of science and technology? What are the implications of Korea’s success for other countries and our understanding of modern economic growth?

I examine these questions in three parts. Section one documents the advance of Korea in science and technology. Section two shows that Korea’s advance in education and research benefited from globalization, as many Korean students obtained higher education overseas and as many Korean scientists engaged in international research collaborations, particularly with the U.S. Section three concludes with potential lessons from Korea’s success in seeking “knowledge, knowledge ... knowledge for (its) economy.”

I. Korea’s Burst in Science and Technology

Table 1 shows where Korea stood in measures of science and technology capability and production circa 2010. The measures cover science and engineering

TABLE 1— KOREA IN LEVELS, RANK IN WORLD AND TRENDS IN S&E RESOURCES AND INNOVATION, CIRCA 2010

	Level, circa 2010	Rank in World	Trend
Science/engineering Degrees	4 165 PhDs (2010)	12th	Doubled since 1996
R&D spending	65.4 billion US \$	5th	Threefold increase in real PPP \$ from 2000 to 2012
Papers	25 593 (2011)	9th	8.8 percent growth a year, second fastest to China among producers of many papers
Patents (USPTO)	13 210 (2012)	3rd	7-fold increase from 1997 to 2012
Innovation (Bloomberg 2014)	92.1 out of 100	1	--
Innovation (Global Innovation Report 2014)	55.3 out of 100	16	Up from 19 in 2007-08 but down from 6 in 2008-09
Innovation (Global Competitiveness Report 2014) Pillar 12 innovation	4.8 out of 7	17	Down from 14 in 2006-07

Source: OECD Main science and technology indicators.

http://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB#

National Science Board, Science and Engineering Indicators, 2014.

<http://www.nsf.gov/statistics/seind14/content/chapter-6/at06-40.pdf>

<http://www.bloomberg.com/visual-data/best-and-worst/> Most innovative in the World 2014: countries

<http://www.globalinnovationindex.org/content.aspx?page=past-reports>

<http://www.weforum.org/reports/global-competitiveness-report-2014-2015>

Global competitiveness Index, 2007-2008, Ranks.

inputs (S&E graduates/researchers and R&D spending), outputs (papers and patents), and aggregate innovation indexes. The statistics document Korea's remarkable position as a substantive player in the global production of S&T knowledge at the outset of the 21st century, notwithstanding its modestly sized population of 50 million and standing in the middle of OECD countries in terms of total GDP.¹ Measuring Korea's commitment to national innovation primarily by the proportion of GDP spent on R&D and the proportion of workers in scientific and engineering activities, Bloomberg rated Korea as the number one innovative economy in 2014.² Looking at a broader set of indicators, including measures of the effectiveness of inputs in transforming the economy, the 2014 Global Innovation Report placed Korea as the 16th most innovative country in the world, while the Global Competitiveness Report put Korea at 17 in its innovation module.³

The principal statistic behind the Bloomberg assessment is the ratio of R&D spending to GDP. Figure 1 shows that the RD/GDP increased in Korea in the 1980s

¹In 2012, Korea was 40th in the world by GDP per capita based on PPP GDP. Korea was at \$32,400, just below the EU at \$34,500 and Japan at \$36,200. The US is 12th on the list at \$49,800. At the top of the GDP per-capita rankings were small oil states and the like. See http://www.photius.com/rankings/economy/gdp_per_capita_2013_0.html

²http://images.businessweek.com/bloomberg/pdfs/most_innovative_countries_2014_011714.pdf This is based on Korea's standing in seven indicators: 1. R&D intensity (20% of score); 2. Productivity (20%); 3. High-tech density (20%); 4. Research concentration (20%) – Professionals, including Ph.D. students, engaged in R&D per 1 million people; 5. Manufacturing capability (10%); 6. Tertiary efficiency (5%); 7. Patent Activity (5%).

³See <https://www.globalinnovationindex.org/content.aspx?page=gii-full-report-2014>; and http://www3.weforum.org/docs/WEF_Global_Competitiveness_Report_2014-15.pdf

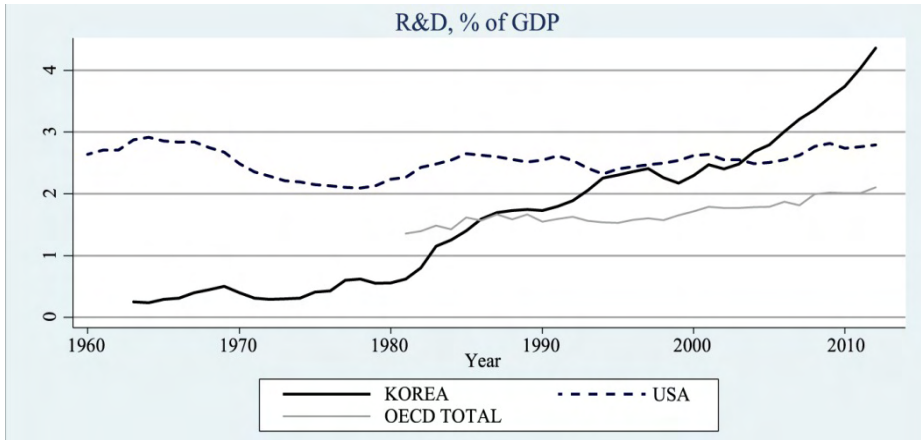


FIGURE 1. KOREA TAKE-OFF AND GROWTH SPURT IN R&D/GDP, 1963-2012

Source: OECD Main Science and Technology Indicators.

through the 2010s from far below the OECD average to far above that average. In the 1960s and 1970s, the Korean R&D/GDP was barely one-third the OECD average – 0.3% to 0.4%. Korea’s investment in R&D in the ensuing decades raised the ratio to 4.36% in 2012.⁴ This put Korea at the top of the OECD, at nearly twice the average R&D/GDP ratio. Other measures of resources going to science and technology show similar increases.⁵

The contribution of a country to global knowledge production depends not on its share of GDP spent on R&D (or related science and technology activities) but on the absolute level of resources – the multiplicand of the R&D proportion of output and the total output, and the effectiveness with which the country uses its R&D to create new knowledge and/or apply research findings to the economy.

Because total resources matter in knowledge creation and application, highly populous countries such as China or India or high per capita GDP countries such as the U.S. can dominate the frontier of knowledge creation or its use while spending smaller shares of GDP on research and development than countries the size of Korea. Smaller/medium-sized countries have to find niches in which to concentrate their R&D investments (as Finland did with Nokia) or have to find ways to leverage global R&D and turn research discoveries worldwide into innovative products or processes produced at home.

To assay the connection between national resources and S&T outcomes among countries, I created a pooled time-series cross-section dataset of country observations on papers and patents, GDP, population, and R&D spending for 37 countries (the 34 OECD countries plus China, Russia, and Singapore) for the years 1981-2011. The data appendix reports the sources of the data, which are downloadable at NBER.

⁴See Lee (2010) Figure 8, p.55.

⁵Ang and Madsen (2009) document the role of R&D in the growth in the “Asian miracle economies,” of which Korea is a prime exemplar, arguing that this fits a Schumpeterian model better than an endogenous growth model.

As a first step for assessing the relationship between the two S&T outcomes and GDP per capita and population, I estimated the following regression in log-log form:

$$\log \text{ of papers or patents} = a + b \log \text{ of GDP per capita} + c \log \text{ of Population} + \\ \text{Year Dummy variables} + \text{Country dummy variables.}$$

GDP per capita and Population measure a country's economic and demographic resources. If the regression of papers/patents yields coefficients on GDP per capita and Population that are roughly comparable, the regression indicates that total GDP is the primary determinant of the outcomes irrespective of whether it is generated by a high GDP per capita or by the size of the population.

Panel A of Table 2 reports the results for papers. Column (1) presents estimates of equation (1) with year dummy variables but without country dummy variables as independent explanatory variables. This means that the coefficients reflect the average cross-section cross-country relationship for the years covered. The estimated coefficients of the log of GDP per capita and the log of Population are sufficiently similar to indicate that total GDP is the predominant determinant of cross-country differences in the numbers of papers. Column (2) gives the results after adding country dummies to the regressions. With country and year held fixed the coefficients measure the average effect of changes in resources within countries on changes in papers and patents. The estimated effects of GDP on papers are larger than in the regressions that include country fixed effects, while the estimated effects of Population are larger but with such a high standard deviation that it is not significantly different from zero. Year-to-year country changes in population are modest, without enough variation to pin down a population effect.

The regressions in columns (3) and (4) of Panel A add the ratio of R&D expenditures to GDP to the regressions of column (1) and (2) as a rough measure of the extent to which a country tilts its resource allocation toward science and technology. The ratio R&D to GDP enters the equation with a large significant coefficient that makes it a major factor in the number of articles. Absent measures of specific country policies toward R&D (such as direct government R&D spending or tax deductions for private spending) or of the factors that cause R&D to vary, the regressions cannot identify the causal impact of R&D policy. These results highlight the importance of R&D as a channel for producing papers.

Panels B and C present similar regressions for patents, and obtain roughly similar results though with greater variation in the estimated coefficients of Population across the regressions. The dependent variable in Panel B is the log of patents reported under the Patent Cooperation Treaty (PCT), which allows applicants to seek protection for an invention in 148 countries simultaneously.⁶ The dependent variable in Panel C is the number of "triadic patent families" – patents filed in the United States Patent Office (USPTO), in the European Patent Office, and in the Japanese patent office (Dernis and Khan 2004). Patents filed in all three locales are potentially more valuable than patents filed in a single location, so the Panel C regressions provide a quality of patent check on the panel B regressions.

⁶<http://www.wipo.int/pct/en/faqs/faqs.html>

TABLE 2—REGRESSION ESTIMATES OF THE EFFECT OF R&D/GDP, GDP/CAPITA, AND POPULATION ON S&E ARTICLES AND PATENTS, POOLED CROSS-SECTION TIME SERIES OF 37 COUNTRIES, 1981~2011

A. Dependent Variable: Ln (Articles)

	(1)	(2)	(3)	(4)
Ln (GDP per capita, in 2005 \$)	1.079*** (0.105)	1.489*** (0.375)	0.772*** (0.162)	1.453*** (0.509)
Ln (Population)	1.030*** (0.096)	1.537 (0.969)	0.935*** (0.056)	0.792 (0.964)
Ln (R&D, % of GDP)			0.556*** (0.171)	0.632*** (0.189)
Constant	-19.705*** (1.812)	-31.583* (15.601)	-14.898*** (2.099)	-18.775 (18.007)
Year FE	Y	Y	Y	Y
Country FE	N	Y	N	Y
Observations	1 067	1 067	947	947
R-squared	0.819	0.971	0.887	0.975

B. Dependent Variable: Ln (Number of Patent Cooperation Treaty Patents)

	(1)	(2)	(3)	(4)
Ln (GDP per capita, in 2005 \$)	1.969*** (0.210)	2.227*** (0.337)	1.016*** (0.123)	1.888*** (0.437)
Ln (Population)	1.090*** (0.081)	4.857*** (1.495)	0.914*** (0.062)	3.060 (2.490)
Ln (R&D, % if GDP)			1.676*** (0.175)	0.840** (0.329)
Constant	-34.153*** (2.419)	-98.781*** (24.984)	-22.095*** (1.917)	-65.603 (41.908)
Year FE	Y	Y	Y	Y
Country FE	N	Y	N	Y
Observations	1 029	1 029	930	930
R-squared	0.776	0.936	0.888	0.939

C. Ln (Number of Triadic Patents), 1985~2011

	(1)	(2)	(3)	(4)
Ln (GDP per capita, in 2005 \$)	2.456*** (0.252)	2.141*** (0.499)	1.469*** (0.127)	2.155*** (0.730)
Ln (Population)	1.244*** (0.089)	2.946*** (0.646)	1.079*** (0.060)	1.491 (0.917)
Ln (R&D, % if GDP)			1.895*** (0.134)	0.853*** (0.210)
Constant	-40.301*** (3.017)	-65.796*** (11.460)	-28.183*** (2.008)	-41.840** (19.444)
Year FE	Y	Y	Y	Y
Country FE	N	Y	N	Y
Observations	935	935	847	847
R-squared	0.779	0.963	0.930	0.971

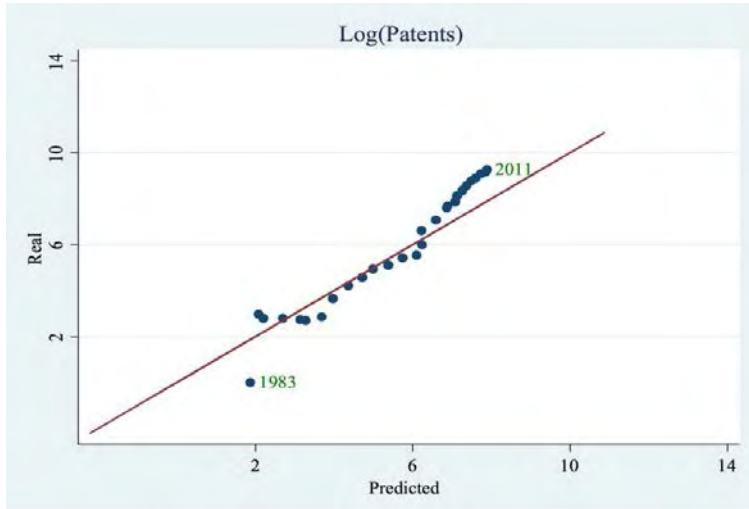
Note: Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Source: See Appendix.

Both panels show that GDP and R&D/GDP are the main determinants of patents while the estimated effects of population per se vary depending on the precise specification.

Finally, Figure 2 contrasts the log of papers and PCT patents for Korea in a given year to the predicted level from the cross-sectional regression on GDP per

Panel A



Panel B

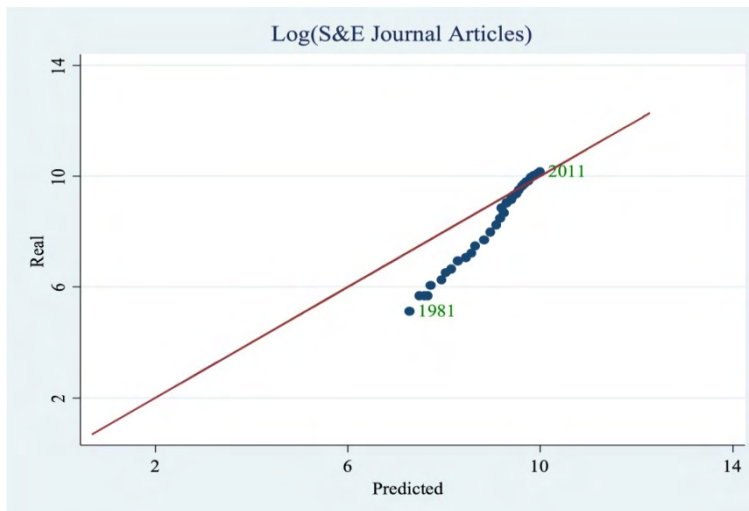


FIGURE 2. PREDICTED AND ACTUAL KOREAN PAPERS AND PATENTS
 (45 DEGREE LINE: ACTUAL = PREDICTED)
 WHERE PREDICTED IS BASED ON REGRESSIONS OF PAPERS OR
 PATENTS ON GDP PER CAPITA AND POPULATION

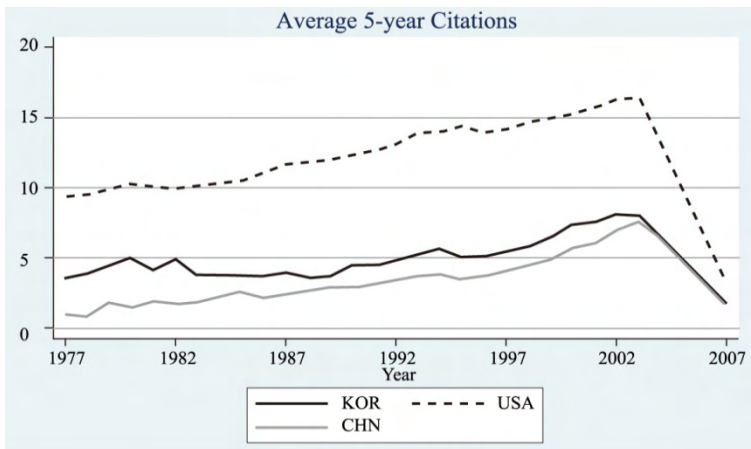
capita and population. Points on the 45-degree line in the figure indicate that a country's papers or patents are as predicted by the model. Points below the line show that the country was not keeping pace with other countries, while points above the line imply that the country produced more papers/patents than indicated by the overall country pattern. In terms of papers, Korea was considerably below the 45-degree line in 1981 but increased publications to roughly reach its expected level by 2009. In patents, Korea hugs the 45-degree line until the 2000s, when it increases its position above that expected from the cross-sectional pattern.

Quality of Papers and Patents

Both papers and patents have important quality dimensions. A paper can be widely cited because it provides valuable information or breakthrough ideas or it may be neglected by the scientific community, perhaps getting no citations at all during some specified time period. Similarly, a patent may have great technological or economic value that leads to a commercial product, or it may be an invention of little relevance.

Measuring paper quality by citations, Figure 3 shows that papers with Korean addresses average about half the number of citations as papers with U.S. addresses and only modestly more than papers with Chinese addresses. Because there is a

Panel A



Panel B

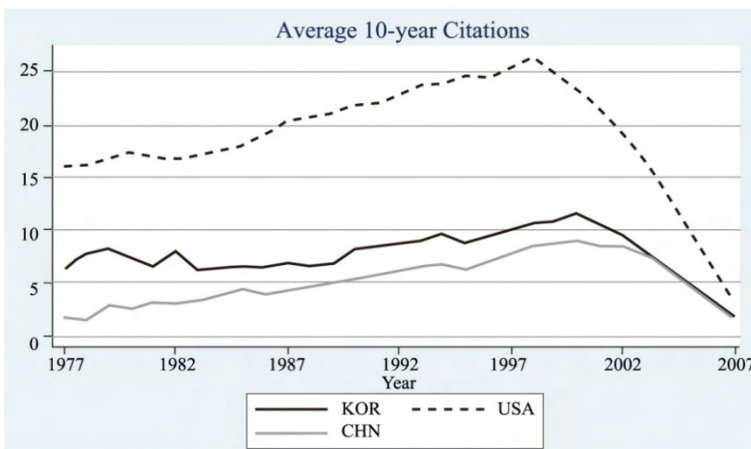


FIGURE 3. AVERAGE FIVE- AND TEN-YEAR CITATIONS OF KOREAN PAPERS, COMPARED TO US AND CHINA, 1977-2007

Source: SCI database.

tendency for persons from a given country to cite papers written in their country (National Science Board, Science and Engineering Indicators 2014, Table 5-26), the high number of citations of U.S. papers is due in part to the U.S. being the top producer of papers. But the difference in the average number of citations almost certainly reflects the intrinsic quality of the work as well.⁷ The U.S. advantage in papers is among the most highly cited papers, where citations come from a wide variety of scientists outside the authors' networks. At the other extreme, the authors of the 20% to 30% of papers that remain uncited must have some network connections with other scientists, who evidently do not view those papers as relevant or useful in their work.

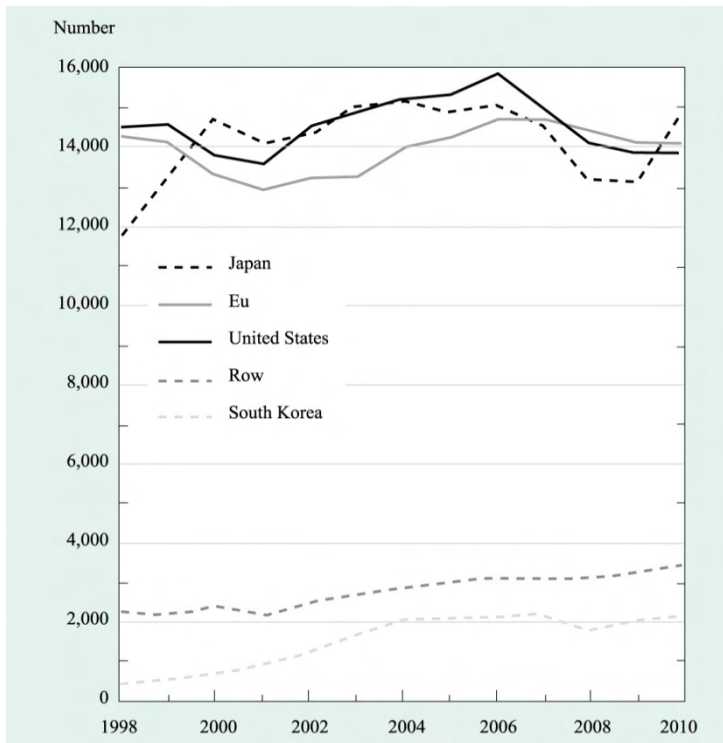


FIGURE 4. KOREA'S INCREASE IN NUMBERS OF TRIADIC PATENTS

notes: EU=European Union, ROW=Rest of World. Triadic patent families include patents applied in the U.S. Patent and Trademark Office, European Patent Office, and Japan Patent Office. Patent families are fractionally allocated among regions/countries/economies based on the proportion of the residences of all named inventors.

source: Organisation for Economic Co-operation and Development, Patents Statistics, <http://stats.oecd.org/WBOS/index.aspx>, Patents by Region database, (accessed 15 January 2011). Cited from Science and Engineering Indicators-overview, 2014, Figure O.16. Global Triadic Patent Families, by Selected Region/Country/Economy: 1998-2010.

⁷Absent a measure of the "intrinsic science quality" of a paper, it is difficult to differentiate the effects of the tendency of scientists in a country to cite own-country research from the actual contribution of the paper. Just as Merton (1968) noted with his "Matthew Effect" that citations for similar work often go to the more famous scientist, the same may be true for scientists from countries with different numbers of scientists.

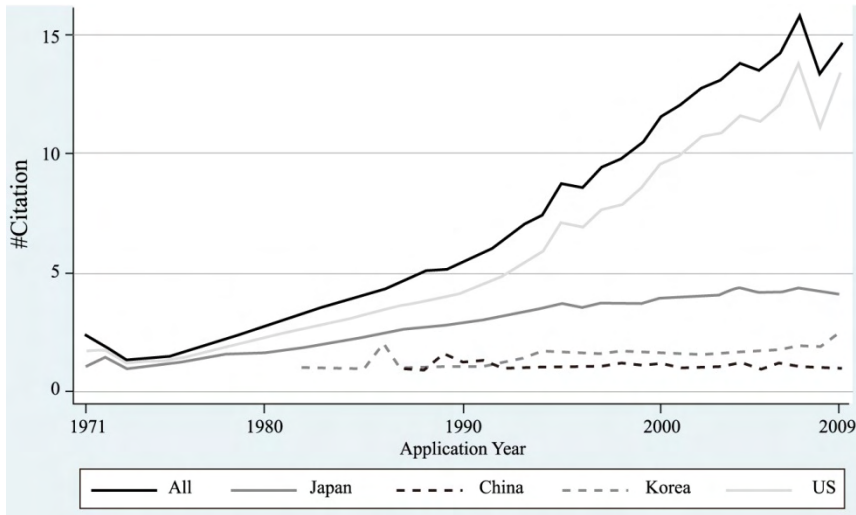


FIGURE 5. AVERAGE CITATIONS IN UPSTO TO PATENTS BY COUNTRY

Source: Kaoru Nabeshima and Kiyoyasu Tanaka (2011), Figure.5.

Indicators of the quality of patents tell a similar but more nuanced story about the potential quality of Korean patents. As noted, one indicator of patent quality is the extent to which a firm patents the same invention in different countries. Figure 4 shows that while the U.S., EU, and Japan dominate the number of triadic patent families, Korea increased its number of triadic patents nearly fourfold from 1999 to 2010. This made Korea the fifth largest country source of triadic patents, falling just short of France.

Another widely used indicator of the potential value of a patent is the extent to which other patents cite that patent.⁸ Figure 5, taken from Nabeshima and Tanaka (2011), shows that the average number of citations of Korean patents, though trending upward, falls short of the average number of citations to all patents and US and Japanese USPTO patents. Korean patents had only modestly higher numbers of citations than Chinese patents.

In short, Korea advanced in the latter part of the 20th century and in the first decade of the 21st century to become a leading country in science and engineering education and research, but the country still had some ways to go to reach the quality of research in the US and other top research countries.

II. Globalization's Contribution to Korea's Advance

The global division of the production of goods and services depends on the comparative advantage of countries in different domains. In Ricardo's famous example, Portugal had a comparative advantage in producing wine and in making

⁸Given that USPTO patent examiners enter many patent citations (Alcácer, Gittelman, and Sampat 2009) and that citations are entered largely for legal reasons, patent citations are only a crude measure of the value of a patent.

clothing over England but had a greater advantage in wine and thus produced it and imported clothing from England. Underlying comparative advantages are differences in resources and knowledge of modes of production. In the “North-South” trade model, the greater educational attainment of workers and R&D in the advanced North gives it comparative advantage in the area of high-value-added products and processes compared to the less advanced South, which allows the North to pay higher wages to its workers.⁹ This model posits that the North’s comparative advantage in human capital and in the production of knowledge was relatively permanent, generating long-term differences in income per head.

Korea’s huge investments in education and science from the 1980s to the present altered its factor endowments from the low education/ knowledge South type to the high education/knowledge North type and transformed its comparative advantage from low-value-added goods and services to high-tech knowledge-based industries. Table 3 documents Korea’s extensive reliance on the growing globalization of higher education to upgrade the university training and doctorate-level research skills of its citizens.¹⁰

Line 1 shows that Korea sent many of its best and brightest students overseas such that in 2012, Korea, with 50 million people, was the third largest source of international students worldwide, trailing only China and India, with their approximately 1.2 billion people each (see Table 3, line 1). The 2012 ratio of international students to population for Korea was .0025, i.e., 400 times the international student/population ratio of .00006 for China and 1,250 times the .00002 ratio for India.

TABLE 3—KOREA’S POSITION AMONG INTERNATIONAL STUDENTS COMPARED TO CHINA AND INDIA IN THE EARLY 2010S

	Korea	China	India
Numbers 2012			
1. Int’l Students	123 700	694 400	189 500
2. Going to US	70 000	210 452	97 120
3. % going to US	56.5%	30.3%	51.3%
4 % increase to US, 2006-2013	19.7%	276.5%	26.5%
Composition of US Int’l 2013			
5 % Undergraduate	54.0%	40.0%	13.0%
6 % Graduate	28.0%	44.0%	56.0%
7 % Other	18.0%	16.0%	30.0%
S&E Composition of Enrollments			
8 S&E % of Undergraduates	27.9%	34.5%	52.5%
9 S&E % of Graduate students	36.8%	61.0%	76.8%

Source: 1. Lines 1-3 <http://www.uis.unesco.org/Education/Pages/international-student-flow-viz.aspx> Other major destinations: China, 97,000 to Japan, 87,000 to Australia; India, 29,000 to UK; 12,000 to Australia; Korea, 24,000 to Japan, 8,000 to Australia; 2. Lines 4- 7, <http://www.iie.org/Research-and-Publications/Open-Doors/Data/Fact-Sheets-by-Country/2013/>; 3. Lines 8-9, National Science Board, Science and Engineering Indicators 2014, Appendix Tables 2-19, 2-28.

⁹See Krugman (1979) for a clear presentation of the model. Gomory and Baumol (2001) argue that loss of a comparative advantage in particular high-value or high-tech industries can reduce the well-being of the county in question. Ruffin and Jones (2007) offer additional insights and a more sanguine view.

¹⁰The number of international student increased nearly eightfold from 600,000 (1975) to 4,500,000 (2012) and more than doubled in the 2000s (OECD 2014, p.344), which exceeded the rapid growth of enrolments in institutions of higher education worldwide.

Line 2 shows that a disproportionate number of Korean (and Chinese and Indian) international students studied in the U.S. Line 3 shows that the likelihood that Korean international students enrolling in the U.S. exceeded the likelihood of Chinese and Indian international students doing so. Line 4, based on slightly different data, shows, however, that with its huge population, China increased the number of international students coming to the U.S. in the 2000s more rapidly than Korea.

Lines 5-7 record the composition of US international students, i.e. undergraduate students, graduate students, and “others” (students who come for short courses or as visitors to gain credit for degrees in their home countries) for Korea, China, and India. Korea had the highest share of undergraduates among international students coming to the U.S. This reflects the desire of many highly educated and wealthy Koreans for their children to obtain a U.S. education, often beginning with high school, to avoid the highly competitive Korean exam system.

Finally, lines 8-9 show that the share of Korean international students seeking science and engineering degrees is the lowest among the three countries at both undergraduate and graduate levels. This is possibly due to the much larger proportion of those who are international students in Korea as compared to the other countries in the table. The first set of international students from a country are likely to be studying science and engineering, which require laboratory equipment and machinery unavailable in their home country. Hence, this expansion involves persons in other fields.

Table 4 compares the numbers of U.S. doctorate graduates from Korea, China, and India with the numbers who obtained doctorate degrees in their home country. The number of PhDs trained in the U.S. are substantial relative to domestic PhD graduates in the three countries, with ratios ranging from 9% to 14% for all doctorates and ratios among science and engineering PhDs ranging from 12% to 27%. In all cases, the ratio of U.S.-educated to home-country educated is higher for Korea than for India and China.

Science and engineering PhDs from outside the U.S. often stay and work in the country for many years. Using Social Security records, Finn (2014) estimated the proportion of S&E doctorates who remain in the U.S. over time. Of the Koreans who earned U.S. PhDs in 2006, 58% were working in the U.S. in 2007 and 42% were still in the U.S. in 2011. These rates compare to stay rates for Chinese and Indian PhDs, which range from 80% to 90%. Data from the Survey of Earned

TABLE 4—COMPARISON OF PhDs IN THE US AND IN HOME COUNTRIES FOR KOREA, CHINA, AND INDIA, CIRCA 2012

	Korea	China	India
All PhDs			
US 2012	1 469	4 217	2 236
Home Country (2010 for Korea and China; 2006 for India)	10 542	48 987	18 370
Ratio of US to Home Country in percentage terms	13.9%	8.6%	12.2%
Science and Engineering PhDs			
US 2012	1 129	3 900	2 129
Home Country (2010 for Korea and China; 2006 for India)	4 165	31 410	7 982
Ratio of US to Home Country in percentage terms	27.1%	12.4%	26.7%

Source: NSF, <http://www.nsf.gov/statistics/sed/2012/pdf/tab26.pdf>
National Science Board, Science and Engineering 2014, Appendix 2-42.

Doctorates on the intention of doctorate recipients with temporary visas to stay in the United States show a similar pattern, with 64% of Koreans intending to stay compared to 87% of Chinese and 86% of Indians (National Science Foundation 2012).

An alternative way to gain insight into the locations of Korean researchers is to examine Web of Science data pertaining to the names and addresses of authors of scientific papers. To identify Korean researchers I used William Kerr's name-ethnicity matching program to assign an ethnic identity to authors (Kerr 2008; Kerr and Lincoln 2010). The identification hinges on the fact that last names such as Kim are likely to be Koreans, while names like Zhang are likely to be Chinese, and so on.

Web of Science papers show a striking change in the locations of Korean-authored papers between the 1980s and the 2000s. In the period of 1985-1998, 44% of first authors (usually the junior person on a collaboration) with Korean names were on papers with U.S. addresses compared to 36% on papers with Korean addresses, whereas in 1999-2007, only 24% had US addresses and 62% had Korean addresses. Looking at papers with Korean last authors (usually the senior person on a collaboration), in 1985-98 31% had U.S. addresses on the paper compared to 52% with Korean addresses. In contrast, during the period of 1999-2007, only 14% of Korean last authors had U.S. addresses while 75% had Korean addresses. Over time, Korea's expanded research activity shifted the locus of Korean researchers from the U.S. to Korea.

Research Collaborations

Scientific research moved in the latter part of the 20th century from individual researchers to teams, producing an upward trend in the number of authors per paper (Wuchty, Jones, and Uzzi 2007; Adams, Black, Clemmons, and Stephan 2005). Papers with more authors tend to be published in journals with high impact factors and garner relatively more citations than those with fewer authors (Wuchty *et al.* 2007; Freeman and Huang 2015), providing a potential productivity justification for increased collaborations.

In the 1990s and 2000s, the increase in scientific collaborations was accompanied by an increase in international collaborations – that is in a growing proportion of papers with coauthors from different countries (National Science Board 2014; Adams 2013).

Table 5 examines the position of Korea and its main scientific collaborators in terms of internationally co-authored papers in 1997 and 2012. The columns entitled “Share of Country S&E Articles Internationally Co-authored” record the ratio of articles with two or more country addresses relative to all articles for the specified group. The shares increase sharply for the world and for most countries, including the U.S.,¹¹ but increase only modestly for Korea and China, whose rapid growth in

¹¹The higher share of internationally co-authored papers for individual countries than for the world arises because the tabulations count an international paper with co-authors from two countries as a single paper at the world level but as two international papers at the country level, with one for each country.

TABLE 5—SHARES OF INTERNATIONAL CO-AUTHORSHIP, KOREA, US, AND MAJOR COLLABORATORS

	Shares of Country's S&E Articles Internationally Co- Authored		Country's Share of Korea's Collaborations		Korea Share of Country's International Collaborations	
	1997	2012	1997	2012	1997	2012
World	15.7	24.9	100.0	100.0	1.8	4.8
South Korea	27.6	30.8	-	-	-	-
US	19.3	34.7	61.5	53.9	2.8	6.0
Japan	16.4	30.0	21.8	15.1	4.4	9.2
China	25.7	26.7	7.4	14.5	3.6	4.7
Germany	35.5	55.5	6.9	9.1	0.07	2.3
United Kingdom	31.0	55.1	5.5	8.8	0.06	2.3
India	22.5	36.7	2.8	8.4	0.3	11.5

Source: Tabulated from Indicators, 2014, Tables 5-56 and 5-41. In 1997 1.8% of worlds 90867 had Korean, in 2012, 4.8 of 211941.

the number of articles was fueled by within-country collaborations.¹²

The columns “Country’s Share of Korean collaboration” record the ratio of papers with at least one Korean address and one address from the specified country divided by the total number of Korean international collaborations. They show that the U.S. has been a huge collaborator with Korean researchers, accounting for 61.5% of Korea’s international collaborations in 1997 and 53.9% in 2012. Japan is the second largest collaborator for Korea, though its proportion of collaborations also dropped. Given China’s huge increase in scientific papers, its share of Korean collaborations increased, but the diversification of Korean collaborations goes beyond China. Germany, the United Kingdom, and India increased their share of Korean collaborations, as did many countries with smaller scientific presence.

The columns “Korea’s Share of Country’s International Collaborations” present the ratio of the number of papers with an address for the given country along with a Korean address divided by the total number of international collaborative papers of that country. Korea’s rapid increase in the number of papers raised its share of the world’s international papers from 1.8% in 1997 to 4.8% in 2012 and also raised its share of international collaborations with the US and all other countries in the table as well. The values of “Korea shares” in the table are lower than those of “other country shares” because even after its rapid increase in the number of papers, Korea published fewer papers than more populous countries or those with longer scientific traditions.

As noted, Korea’s citation performance lags behind its production of papers and patents. One likely reason for this is that it takes time for new researchers and labs to develop the tacit knowledge that often produces better work. Another is that scientists from Korea lack the network connections of scientists from more established research countries that help produce greater rates of acceptance in prestigious journals and produce many citations. Examining Korean scientific journals included in the Science Citation Index, Park and Leydesdorff (2008) find that even though the journals are published in English, Korean authors in international journals hardly quote papers published in them, which minimizes their contribution as part of a Korean network of scientists citing each other.

¹²Looking over shorter different periods, Kim (2005) notes declines in the proportion of international collaborations in Korea associated with its growth spurt in papers.

TABLE 6—ESTIMATED RELATIONSHIP BETWEEN US AND OTHER OVERSEAS PUBLICATION EXPERIENCE ON IMPACT FACTORS AND FIVE-YEAR CITATIONS OF PAPERS WITH KOREAN ADDRESSES AND ALL AUTHORS WITH KOREAN NAMES

Variables	1	2	3	4
	Impact Factor	5-year Citations	Impact Factor	5-year Citations
USA experience	0.301*** (0.102)	1.077*** (0.413)	0.260*** (0.0958)	1.083** (0.437)
Other oversea experience	-0.207* (0.120)	1.325** (0.647)	-0.287** (0.113)	0.955 (0.633)
Observations	9 120	9 120	9 068	9 068
R-Squared	0.368	0.251	0.413	0.292
Author Number	No	No	Yes	Yes
Address Number	No	No	Yes	Yes
Reference Number	No	No	Yes	Yes
Publication year	Yes	Yes	Yes	Yes
Field	Yes	Yes	Yes	Yes

Note: Robust standard errors in parentheses. Papers are published no earlier than 1990.

*** p<0.01, ** p<0.05, * p<0.1.

Source: Tabulated from papers in PubMed with citations from Web of Science, 1990-2007.

Since international collaborations link Koreans and scientists from countries with larger and more established scientific systems, such collaborations offer a channel to increase the impact of Korean scientific work. Koreans writing papers in institutions outside the country would benefit from the tacit knowledge and the connections among persons working for the institutions. Koreans returning to the country with publication experience outside the country should be able to leverage that experience to conduct more impactful research.

Table 6 examines how Korean authors writing their papers in Korea who had overseas experience, defined as having a prior paper with an address overseas and no address in Korea, fared in the impact factor of the journal of publication and in the number of citations to their paper relative to authors in Korea with no such experience. Since it is necessary to disambiguate the names of individual scientists to determine if they have an earlier English-language paper, I use PubMed data, for which Torvik and Smalheiser (2009) have developed a sophisticated algorithm for differentiating individuals with the same name. The first two columns include covariates for the language of the journal, the country publication year and the detailed field as reported in the Web of Science. The last two columns include three variables that reflect the characteristics of the article, i.e., the number of authors, number of addresses, and the number of references on the article, all of which previous research finds are positively related to impact factors and citations (Freeman and Huang 2015). The regressions show that U.S. experience overseas pays off in higher impact factors while other overseas experience is associated with lower impact factors. This pattern could reflect that work experience in the U.S. produces better papers for Korean researchers, but it could also be due to the fact that the U.S. publishes most in impact journals, so that Koreans with only non-U.S. experience are disadvantaged on that measure. Both U.S. experience and other overseas experience are associated with greater five-year citations than are obtained by Korean researchers without overseas experience. While the magnitude of the coefficients differ somewhat, they are not statistically significantly different.

This result suggests that the impact factor difference between the papers by Koreans with U.S. experience and non-U.S. overseas experience may be more reflective of the location of high impact journals than of the quality of the actual work.

To see how Korean researchers working outside the country fare in their publications, I examine next the relationship between having a Korean first or second author on a paper with all addresses outside Korea and the impact factor of the journal of publication and the five-year forward citations of papers. To identify Korean authors, I use William Kerr's name-ethnicity matching program (Kerr 2008; Kerr and Lincoln 2010), which assigns an ethnic identity to authors based on the distribution of names by ethnicity. The identification hinges on the fact that last names such as Kim are especially likely to represent Koreans while names like Zhang are likely to be Chinese, and names like Johnson likely to be Anglo-American.

Table 7 records the regression coefficients and standard errors on the Korean ethnicity of first and last authors, with the first two columns including covariates for the language of the journal, the country publication year and a detail field as reported in the Web of Science. The last two columns include the number of authors, the number of addresses, and the number of references to the article. The regressions yield similar findings. All of the estimates for first authors having Korean names are positive, indicating that these researchers produce papers that have higher quality by the impact factor and citation indicators than first authors with names with other ethnicities. The estimates for last authors being Korean show negative effects on impact factors and positive but statistically insignificant effects on citations. One likely reason for the positive performance of first-author Koreans is that they have been positively selected from Korean researchers compared to all overseas researchers in their field who have not been so positively

TABLE 7—ESTIMATED RELATIONSHIP BETWEEN FIRST AND LAST AUTHOR HAVING KOREAN NAMES IN PAPERS WITH NON-KOREAN ADDRESSES AND THE IMPACT FACTOR OF THE JOURNAL OF PUBLICATION AND FIVE-YEAR CITATIONS

Variables	1	2	3	4
	Impact Factor	5-year Citations	Impact Factor	5-year Citations
First Author Korean	0.0216 (0.014)	0.086*** (0.115)	0.0175*** (0.0137)	0.470*** (0.113)
Last Author Korean	-0.0702*** (0.0184)	0.169 (0.151)	-0.0768 (0.0181)	0.0550 (0.149)
Observations	6 036 718	6 036 718	5 937 464	5 937 646
R-Squared	0.376	0.122	0.388	0.168
Author Number	No	No	Yes	Yes
Address Number	No	No	Yes	Yes
Reference Number	No	No	Yes	Yes
Language	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes
Publication Year	Yes	Yes	Yes	Yes
Field	Yes	Yes	Yes	Yes

Note: Standard errors in parentheses.

*** p<0.01, ** p>0.05, * p<0.1.

Source: Tabulated from papers in PubMed with citations from Web of Science, 1990-2007.

selected. The lower impact factors for last-author and presumably senior Korean researchers may reflect their being more poorly connected to the network of scientists outside Korea than comparable researchers in those countries or possibly to their being not as skilled as their younger cohorts.

Finally, a number of studies show that papers for which Koreans in Korea collaborate with researchers outside the country produce are more impactful than those resulting from collaborations of researchers within the country.¹³ Since Koreans collaborate disproportionately with researchers in the U.S., which has exceptionally high impact factors and numbers of citations, it would be shocking if this were not the case.

All told, international experiences appear to improve Korean research, with Koreans generally doing well working in overseas locations, with those returning home having better research performance than researchers without overseas experience, and through international collaborations.

III. Globalization's Conclusion: Lessons from Korea's Experience

Korea's moving to the frontier of science and engineering in the 1980-2010 period was a remarkable achievement. Developing a powerful science and technology knowledge creation machine literally from scratch and using knowledge to catch up with advanced countries and transition from being a developing country with a comparative advantage in low skill low wage goods and services to an advanced country with a comparative advantage in the knowledge economy has broad implications for economic development in today's world.¹⁴ At the risk of oversimplifying a complicated process, I draw five lessons from Korea's commitment to a "Knowledge, knowledge, knowledge ... knowledge for my economy" model of economic growth.

The first and perhaps most important lesson is Korea's proof of reality that in the modern era, a developing country can transform itself and its comparative advantage in the world economy in the space of 30 or so years. Few if any development economists would have believed this to be possible three or four decades ago. With knowledge – a unique public good – at its base, the S&T based economy offers ways of telescoping economic development.

The second lesson from Korea's experience is the role played by activist governments through industrial policy. The OECD (2009, 2014), the World Bank Institute (2007), Korean government agencies (the Korea Information Society Development Institute and the Korea Ministry of Science, ICT, and Future

¹³Kim (2007) shows that Korea's Biotechnology Stimulation Plans (1994-2007) produced a burst of bio-tech papers but little increase in terms of impact factors of journals for Korean publications, while international collaborations produced more publications in mainstream journals with high impact factors than local and domestic collaborations. Chung (2002) provides a broad view of Korea's use of international links to upgrade its science and technology. Kwon et al. (2012) argue that international collaborations came at a cost of stagnation of the cross-connection within Korea among different research entities.

¹⁴Korea's share of global value added in knowledge intensive industries increased (National Science Board, 2014, Appendix Table 6-2). In technology, Korea's ICT R&D produced WiBro (<http://en.wikipedia.org/wiki/WiBro>), which is widely used in Korea and has been adopted as an ITU international standard; and DMB.

Planning 2014) and diverse researchers (Bartzukis 2008; Campbell 2012; Doh and Kim 2014; Lee *et al.* 2013; Min and Kim 2013; Lee, Son, and Om 1996; among others) have examined specific policies by which Korea sought to galvanize the country in this jump: public research institutes, support of university education and research, the setting of goals, and the support of particular industries.

A detailed study and an assessment of how Korea might have developed with different policies or through the implementation of policies is needed to determine what worked most/least effectively and what is/is not transferable to other countries. But it is difficult to gainsay that Korea succeeded through activist governments setting industrial policy and thus to maintain the shibboleth that markets alone suffice to produce modern economic growth.

The third lesson is the theme stressed in section 2 of this paper: that Korea made the jump to a modern knowledge-based economy with help from the globalization of higher education and international research collaborations, and in particular from its close ties to the U.S.

The fourth lesson is that Korea did all this with a democratic government, with citizens regularly electing presidents from competing parties or factions of parties and with open political debate in the parliament and country.

Finally, the Korean case also shows that movement to a knowledge economy does not by itself resolve economic problems. It transforms some problems, eliminates some, but leaves others festering or possibly contributes to them. Korea's economic advance to a knowledge economy has not reduced the high proportion of workers in non-regular work nor substantial gender differentials, nor has it reduced the polarization of jobs between low productivity services and high productivity manufacturing, and so on. What Korea's new position as a research power has done has given it additional tools for addressing these and other problems to improve the well-being of citizens broadly. Knowledge, knowledge, knowledge, knowledge for my economy? – Yes, yes, yes.

APPENDIX

Data Source for Table 2

- Population:
<http://data.worldbank.org/indicator/SP.POP.TOTL?display=default>
- GDP in constant 2005 dollars:
<http://data.worldbank.org/indicator/NY.GDP.MKTP.KD?display=default>
- Scientific and technical journal articles:
<http://data.worldbank.org/indicator/IP.JRN.ARTC.SC?display=default>,
- Patent applications filed under the Patent Cooperation Treaty (PCT) and Triadic Patents come from OECD, at <http://stats.oecd.org/>
- R&D expenditures as a share of GDP come from three sources a-c:
 1. NSF Science and Engineering Indicators 2014 for the United States at <http://www.nsf.gov/statistics/seind14/index.cfm/appendix/tables.htm>, table at04-01.
 2. Lee (2010) for South Korea, Figure 8, with interpolations for missing years.
 3. OECD Stat Extracts at http://stats.oecd.org/Index.aspx?DataSetCode=GERD_FUNDS#

In total we have 31 years of data for the 34 OECD countries plus China, Russia and Singapore, but our data are not sufficiently complete to have 1,147 (= 31*37) observations. There are 50 country-year observations with article count missing, and 18 observations with zero articles. Missing values in GDP or population reduce the usable observations for Panel A column (1) down to 1,067. The data for PCT-Patent is available for every year and every country, but entirely missing for Singapore. There are 72 country-year cells with zero PCT-patent. This makes the observations in column (5) different from that in column (1). For Korea, 1981 and 1982 have PCT-PAT=0. Starting from 1983, Korea has positive patent count fast growing. The triad patent data begin in 1985, reducing the sample in Panel C.

REFERENCES

- Adams, J.** 2013. "Collaborations: The Fourth Age of Research." *Nature* 497 (7451): 557-560.
- Adams, J., G. Black, J. Clemmons, and P. Stephan.** 2005. "Scientific Teams and Institutional Collaborations: Evidence From US Universities, 1981-1999." *Research Policy* 34 (3): 259-285.
- Alcácer, J., M. Gittelman, and B. Sampat.** 2009. "Applicant and Examiner Citations in U.S. Patents: An Overview and Analysis." *Research Policy* 38 (2): 415-427.
- Ang, J., and J. Madsen.** 2009. "Can Second-Generation Endogenous Growth Models Explain The Productivity Trends and Knowledge Production In the Asian Miracle Economies?" MPRA Paper (17543).
- Bartzokas, A.** 2008. "Monitoring and Analysis of Policies and Public Financing Instruments Conducive to Higher Levels of R&D Investments." The "POLICY MIX" Project: Country Review Korea, UNU-MERIT.
- Bloomberg.** "Most Innovative in the World 2014: Countries." Last modified 2014. http://images.businessweek.com/bloomberg/pdfs/most_innovative_countries_2014_011714.pdf
- Bound, J., S. Turner, and P. Walsh.** 2009. "Internationalization of US Doctorate Education." NBER Working Paper 14792, <http://www.nber.org/papers/w14792>
- Campbell, J.** 2012. "Building an IT Economy: South Korean Science and Technology Policy." *Issues in Technology and Innovation* 19, Brookings Institution at <http://www.brookings.edu/research/papers/2012/09/12-korean-technology-campbell>
- CIA World Factbook.** 2013. "GDP per capita (PPP) 2013 Country Ranks, By Rank." Countries of the World. Last modified March 13, 2013. http://www.photius.com/rankings/economy/gdp_per_capita_2013_0.html
- Chung, S.** 2002. "Catch up Through International Linkage, Science, Technology and the Korean Experience." *Science and Public Policy* 29 (6): 431-437.
- Dernis, H., and M. Khan.** 2004. "Triadic Patent Families Methodology." OECD Science, Technology and Industry Working Papers 2004/02, OECD Publishing, Paris.
- Doh, S., and B. Kim.** 2014. "Government Support for SME Innovations in the Regional Industries: The Case of Government Financial Support Program in South Korea," *Research Policy* 43: 1557-1569.
- Dutta, S., B. Lanvin and S. Wunsch-Vincent.** 2014. "The Global Innovation Index 2014: The Human Factor Innovation." [Globalinnovationindex.org](http://globalinnovationindex.org). Last modified 2014. <https://www.globalinnovationindex.org/content.aspx?page=gii-full-report-2014>;
- European Association of Science Editors.** 2007. "The EASE Statement on Inappropriate Use of Impact Factors," http://www.ease.org.uk/sites/default/files/ease_statement_ifs_final.pdf
- Finn, M.** 2014. "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2011." Oak Ridge Lab, <http://orise.orau.gov/files/sep/stay-rates-foreign-doctorate-recipients-2011.pdf>
- Freeman, R.** 2013. "One Ring to Rule Them All? Globalization of Knowledge and Knowledge Creation" NBER Working Paper 19301: 11-43.
- Freeman, R., and W. Huang.** 2015. "Collaborating with People Like Me: Ethnic Co-Authorship within the U.S.," NBER Working Paper No. 19905.
- Gomory, R., and W. Baumol.** 2001. *Global Trade and Conflicting National Interests*. Cambridge, MA : MIT Press,.
- Hegde, D., and B. Sampat.** 2009. "Applicant Citations, Examiner Citations, and the Private Value of Patents." *Economics Letters* 5 (3): 287-289.
- Hu, A., and A. Jaffe.** 2003. "Patent Citations and International Knowledge Flow: The Cases of Korea and Taiwan." *International Journal of Industrial Organization* 21 (6): 849-880.
- Hu, A.** 2009. "The Regionalization of Knowledge Flows in East Asia: Evidence from Patent Citations Data." *World Development* 37 (9): 1465-1477.
- International Mathematical Union.** 2008. "Joint IMU/ICIAM/IMS Committee on Quantitative Assessment of Research Citation Statistics," <http://www.mathunion.org/fileadmin/IMU/Report/CitationStatistics.pdf>
- Kerr, W., and W. Lincoln.** 2010. "The Supply Side of Innovation: H-1B Visa Reforms and U.S.

- Ethnic Invention,” *Journal of Labor Economics* 28 (3): 473-508.
- Kerr, W.** 2008. “Ethnic Scientific Communities and International Technology Diffusion.” *The Review of Economics and Statistics* 90 (3): 518-537.
- Kim, Mee-Jean.** 2005. “Korean Science and International Collaboration, 1995–2000.” *Scientometrics* 63 (2): 321-339.
- Kim, Mee-Jean.** 2007. “A Bibliometric Analysis of the Effectiveness of Korea’s Biotechnology Stimulation Plans, with a Comparison with four Other Asian Nations.” *Scientometrics* 72 (3): 371-388.
- Kingston, W., and K. Scally.** 2006. *Patents and the Measurement of International Competitiveness New Data on the Use of Patents by Universities, Small Firms and Individual Inventors*, Edgar Elgar Publishing, Northampton.
- Korea Information Society Development Institute and Korea Ministry of Science.** 2014. “ICT, and Future Planning, Knowledge Sharing Program.” ICT R&D and Policy Government Publications (11-1051000-000449-01).
- Krugman, P.** 1979. “A Model of Innovation, Technology Transfer, and the World Distribution of Income.” *Journal of Political Economy* 87 (2): 253-266.
- Kwon, Ki-Seok, HanWoo Park, Minho So, and L. Leydesdorff.** 2012. “Has Globalization Strengthened South Korea’s National Research System? National and International Dynamics of the Triple Helix of Scientific Co-Authorship Relationships in South Korea.” *Scientometrics* 90: 163-176.
- Lee, M., Byoungso Son, and Kiyong Om.** 1996. “Evaluation of National R&D Projects in Korea.” *Research Policy* 25: 805-818.
- Lee, Jeong Hyop.** 2010. “Evolution of Republic of Korea’s R&D System in a Global Economy.” http://nis.apctt.org/PDF/CSNWorkshop_Report_P2S2_Lee.pdf
- Lee, Sang Hyon, Hayoung Cho, and Daeryeok Lee.** 2013. “Analysis of Performance-Improving Factors of International R&D Collaborations Conducted by Universities in South Korea.” *Asian Research Policy* 4 (2).
- Merton, R.** 1968. “The Matthew Effect in Science.” *Science* 159 (3810): 56-63.
- Min, JaeWoong, and YoungJun Kim.** 2013. “Determinants of Corporate Commercialization of Public Technology Transfer: Evidence in Korea.” *Asian Research Policy* 4 (2).
- Nabeshima, K., and K. Tanaka.** 2011. “Innovation Networks in China, Japan, and Korea: Further Evidence from U.S. Patent Data.” IDE Discussion Paper (297).
- National Science Foundation.** 2012. “Survey of Earned Doctorates.” <http://www.nsf.gov/statistics/sed/2012/pdf/tab53.pdf>
- National Science Board.** 2014. *Science and Engineering Indicators 2014*, National Science Foundation (NSB 14-01), Arlington, VA.
- OECD.** 2009. *Reviews of Innovation Policy Korea*. OECD Publishing, Paris, France.
- OECD.** 2014. *Education at a Glance 2014: OECD Indicators*. OECD Publishing, Paris, France. <http://dx.doi.org/10.1787/eag-2014-en>
- OECD.** 2014. *Industry and Technology Policies in Korea*, OECD Publishing, Paris, France.
- Park, HanWoo, and L. Leydesdorff.** 2008. “Korean Journals in the Science Citation Index: What Do They Reveal About the Intellectual Structure of ST in Korea.” *Scientometrics* 75 (3): 439-462.
- Ruffin, R., and R. Jones.** 2007. “International Technology Transfer: Who Gains and Who Loses?” *Review of International Economics* 15 (2): 209-222.
- Suh, Joonghae, and D. Chen.** 2007. *Korea as a Knowledge Economy: Evolutionary Process and Lessons Learned*, World Bank, Washington, DC.
- Torvik, V., and N. Smalheiser.** 2009. “Author name disambiguation in MEDLINE.” *ACM Transactions on Knowledge Discovery from Data* 3 (3): 11.
- Wuchty, S., B. Jones, and B. Uzzi.** 2007. “The Increasing Dominance of Teams in Production of Knowledge.” *Science* 316 (5827): 1036-1039.