

# Research output and economic output: a Granger causality test

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## Abstract:

The correlation between GDP and research publications is an important issue in scientometrics. This article provides further empirical evidence connecting revealed comparative advantage in national research with effects on economic output. Using quantitative time series analysis, this study attempts to determine the nature of causal relationships between research output and economic growth. One empirical result is that there is mutual causality between research and economic growth in Asia, whereas in Western countries the causality is much less clear. The results may be of use to underdeveloped nations deciding how to direct their investment: toward education, infrastructure and engineering, or more toward fundamental science.

## Keywords:

Research output, economic productivity, time series analysis, granger causality

## I. Introduction

The correlation between GDP and research publications is an important issue in scientometrics. However, previous studies have not provided clear evidence as to the direction of causality, i.e. whether GDP affects the number of publications or number of publications affects GDP. Past studies have also not considered the lead-lag effects between the two time series of GDP and publications.

King (2004) finds that each country has its own particular research strengths. There are also differences in the ways in which particular scientific disciplines interact with the economy. For example, the pharmaceutical industry requires extensive research in both animals and humans to bring a product to market. By contrast, much less basic research is required for

engineering products. Therefore the specific areas of scientific research in which a country excels may be an important factor in the strength of the link between scientific output and economic strength. This variation has been relatively underexplored in the literature.

There is a body of literature examining the link between economic growth and research output. King (2004) looks at historical data to assess the link between economic performance and number of research articles published, and finds for the most part that there is a linear or exponential relationship between them. Price (1978) and Kealey (1996) find a linear relationship between indices measuring research output and economic growth. Vinkler (2008) considers the impact of level of development on research output. His empirical conclusion is that the relationship between economic growth and research performance varies depending on a country's level of development. Among highly developed nations, he finds there to be no significant link between economic performance and research. By contrast, in Central and Eastern European countries, Vinkler finds a much clearer link between economic development and research output. He suggests that highly developed nations have the ability to support the cost of research, so their research includes fundamental science, not focused on immediate needs. The link between research and economic performance is therefore broken for developed nations.

The selection of priority areas for research is an important matter for a state or an organization. It is one of the key features of a science policy. Rai & Lal (2000) suggest that underdeveloped nations should focus their research investment in the areas of education, infrastructure and engineering, while more developed nations have the capacity to invest in fundamental research which is not immediately applicable, but may be of value in future. The reasoning of Rai & Lal rests on the assumption that some areas of research have a greater impact on economic development than others. Hung, Lee & Tsai (2009) find that Singapore, South Korea and Taiwan have increased their research output at a particularly high rate over the last ten years; Chuang, Lee, Hung & Lin (2010) find that the research areas in which these three countries have the most significant achievements tend to be related to engineering.

Newly industrializing economies (NIE), especially South Korea, Taiwan and Singapore, have tended to focus on the understanding and diffusion of existing technology rather than the development of original technologies.

Since that early period, many of the skills and processes required in reverse engineering have been redeployed in R&D programs. Rapid growth in science and technology investment has been guided by industry and concerns for competitiveness, with a strategic focus on industrial development. For these countries, the relationship between economic development and R&D investment may fit neither the general model described by King (2004) nor the Vinkler (2008) pattern.

The question of causality – whether research excellence promotes economic growth or economic growth supports advances in research – is a difficult one to answer empirically. If there is causation in both directions, then each causal mechanism will include a time lag. Ignoring this lag inevitably leads to invalid results, making causality impossible to establish.

Though the correlation between research and economic growth is well established, there has been a lack of research into the causality in this relationship. We are also interested in how research priorities correlate with economic development, and this question has been largely ignored in the literature to date. This study aims to improve on measurement methodologies and to use more precise data to explore the relationship between national research areas and economic growth. We hope these results will provide some precise empirical data for the ongoing project to research the link between research and economic development.

## **II. Data & Methodology**

The indices for research and economic production are: number of publications and GDP (million USD). Time series were generated using annual data for the number of Taiwanese publications in SCI and SSCI indexed journals and annual GDP data for the period 1981 to 2007. Nominal GDP data in US dollars were taken from the International Monetary Fund's (IMF) World Economic Outlook Database (2009/4). Publication data were taken from the National Science Indicators (NSI) database compiled by the Institute for Scientific Information (ISI), part of Thompson Reuters. The NSI is a database constructed from citations in the ISI Web of Knowledge (WoK). It includes indicators for research publications from every country. For the purposes of this paper, publications are those indexed in the 3600 Science Citation Index (SCI) categories and 1810 Social Sciences Citation Index (SSCI).

Subsequently, we used the categorization of countries and research areas

developed by Chuang et al. (2010) to assess the link between research priorities and economic growth. The revealed comparative advantage (RCA) index calculates the relative advantage of countries in each specific research area. Clustering analysis was then used to sort the countries into four groups.

**Group 1:** Austria, Switzerland, Germany, France, Italy, Belgium, Finland, Sweden, Denmark, Spain, and Brazil. This cluster includes most developed European nations and Brazil. Group 1's comparative advantages are in medicine, life sciences, and natural sciences.

**Group 2:** Australia, Canada, Norway, Netherlands, UK, USA, and Israel. Group 2 has comparative advantages in all scientific fields except for those directly related to industry: chemistry, physics, engineering, and material science.

**Group 3:** South Korea, Singapore, and Taiwan. These three nations are three of Asia's Four Little Dragons. These three NIEs have advantages in computer science, engineering and material science. Advantages in medicine and life science are less prominent. Taiwan and Singapore also have RCA in economics and business.

**Group 4:** China, India, Japan and Poland. Like Group 3, Group 4 nations have comparative advantages in high-technology fields.

The analysis of relationships between research area and economic growth is based on this four-way categorization.

The Granger causality test is used to demonstrate casual relationships between time series. Granger (1980) defines Granger causality as: "A time series variable X Granger causes Y, if the probability of Y conditional on its own past history and the past history of X does not equal the probability of Y conditional on its own past history alone." Using this concept, it is possible to assess whether GDP causes publications or vice-versa.

There are thus two hypotheses:

**Hypothesis 1:** The number of publications is useful in forecasting GDP.

This hypothesis imagines a situation in which research has a direct impact on economic growth. If publications is not useful in forecasting GDP, it is still possible that basic research is being conducted into fundamental science which may supply future potential needs.

**Hypothesis 2:** GDP is useful in forecasting the number of publications.

This hypothesis imagines a situation in which industry drives investment in research. If GDP is not useful in forecasting the number of publications, then research is being driven not by industry but by other potential opportunities.

Vector autoregression (VAR) is a popular model used in econometrics to capture the evolution and the interdependencies between multiple time series. Combined with vector autoregression, the Granger causality test can provide further evidence for causality relationship between GDP and number of publications. (Green, 2003)

### **III. Empirical results**

Between 1981-2007, the average rate of economic growth across all the countries in the sample was 7.77% per year. Growth was highest in Group 3, at 10.31%; followed by Group 4, at 8.84%; with Groups 1 and 2 achieving lower levels of growth. Late-developing nations can observe and learn from the experiences of early developers to shorten the development process, hence the faster growth in Groups 3 and 4. Group 1 exhibits greater volatility in growth rates than Group 2. Two distinct periods can also be observed: from 1982 to 2000, the late-developing Group 3 nations grew very fast based on their manufacturing strength. After 2001, European currencies strengthened against the dollar, so in the 2001-2007 period, Group 1 countries have a higher GDP growth rate, while Group 3 nations, with weaker currencies, show slightly slower growth for this period.

The fastest growing countries are the emerging economies Singapore, South Korea and Poland. The slowest growing are the USA, Sweden and Japan. Volatility is lowest for the USA, while South Korea is an example of a high growth, high volatility pattern. South Korea's high volatility may be connected to its dependence on exports and on large companies.

[ Insert Table 1 Here]

The average growth in publication volume across all countries for the period 1981-2007 was 19.30% per year (Table 2). Publications increased fastest in Group 3, at 28.30%. Group 3 nations have a comparative advantage in the areas of computer science, engineering and materials science. The fastest increases (over 40% per year) came in the 1980s because of the low baseline of research these countries were starting from. Growth in publications

slowed in the 1990s and 2000s. In fact, all countries experienced fast growth in the number of publications in the 1980s as the number of journals increased and ISI expanded the coverage of its indexing.

[ Insert Table 2 Here]

The correlation between GDP and publications is illustrated in Table 3. Correlation coefficients are high for GDP and research publication for all countries in the sample analyzed here (77.7%-99.6%); simply looking at this relationship, we would conclude that the link between research and economic growth is strong. Taking both economic growth and publication growth together, the correlation in Group 1 and 2 countries is fairly flat (Figure 1), while for Group 3 and 4 countries the correlation is more obvious (Figure 2). This result is consistent with the empirical evidence presented by Vinkler (2008). Vinkler suggests that the nature of the link between research and growth varies depending on features of the country in question. He finds that there is no significant correlation between economic performance and research performance for economic developed countries; while for economic developing countries the correlation is significant.

[ Insert Table 3 Here]

[Insert Figure1 & Figure 2 Here]

Both economic productivity and research production are highly time-dependent variables. The time series developed from the data are therefore non-stationary. Granger and Newbold (1974) note that when analyzing non-stationary time series there is a possibility of spurious regression, which could make two unconnected variables appear to be causally related. In this study, it is necessary to test for a unit root in the GDP and research publication time series for each country. For this purpose and augmented Dickey-Fuller (ADF) test was used, based on Dickey & Fuller (1979, 1981).

The tests demonstrated that all of the time series are non-stationary (Table 3). For example, Austria's GDP is an I(1) series, meaning that the first order difference of the series is stationary. However, its research productivity is I(2): the second order difference of the series is stationary. Past analyses, which have used only regression to trend or correlation analysis have ignored problem that the series are non-stationary. For this study, the series are detrended to produce stationary processes before testing for causal

correlations. This is a necessary step for a full correlation analysis.

[ Insert Table 4 Here]

The results following detrending show that there is significant correlation between growth and research for Group 3 countries. Moreover, there is mutual causation: research production affects economic productivity, and increases in economic productivity in turn affect research production. Among the Group 4 countries, there was also mutual causality between research and economic growth for Japan.

In Groups 1 and 2, research output is a causal factor in economic growth in Austria, Germany, Australia and the Netherlands. Economic productivity affects economic growth in Spain, Israel, Norway and the USA. So for about half of the countries in Groups 1 and 2, there is a one-way causal relationship, either research→economy or economy→research. For the other countries in Groups 1 and 2, there is no significant causal relationship between research production and the economy. However, this does not mean that academic production is of no assistance to economic development, or that economic development does not affect research priorities. Rather, it may mean the relationship between the two is subtle, or that government investment in fundamental research is aimed at enhancing the potential for long term development

The three countries in Group 3 all exhibit mutual causality between research and economic productivity. This may be connected with an approach to fundamental research common to all of these countries. They are all late developers, whose economies have developed primarily by taking over manufacturing from developed nations. Their industrial development has guided their science and technology policies, and they have deployed science and technology to improve industrial processes and productivity.

Governments attempt to create favorable conditions for firms to operate, and to reduce the risk of major investments in advanced technologies (Mathew, 1996). Marsh (1997) and Dodgson (2000) analyze the industrial strategies of East Asian nations, and they find that these nations concentrate heavily on high-tech industries, especially electronics. OEM systems and reverse engineering activities enable NIEs to import technologies and information, to develop in-house expertise, learn by trial-and-error, provide on-the-job training, and to understand the market. They are able to learn from the

practices of transnational corporations (TNC) from developed nations, emphasizing quality, delivery and price of products (Hobday, 2000).

By contrast, causal relations between research and economic growth are weak for rich nations (Groups 1&2). This study supports the conclusion of Vinkler (2008). Vinkler (2008) finds that in European Community member states, the US and Japan, the correlation between the GDP and number of publications for a given year is not significant. This empirical result may imply that grants for scientific research in rich countries are targeted primarily at enhancing future potential growth rather than on immediate industrial requirements.

#### **IV. Conclusion**

Time series analysis shows that GDP and academic output are highly time dependent. Therefore quantitative time series techniques are necessary for handling these series. After eliminating time dependence, it is clear that not every country exhibits the strong positive correlation between research output and economic output that a simple analysis appears to show.

NIEs focus on technology learning and diffusion rather than on developing new technologies. Their research tends to focus on investigation of existing production technologies. In western countries, the link between research output and economic output is weaker, suggesting that the relationship between economic development and R&D investment may be neither the commonly assumed positive correlation, nor the relationship posited by Vinkler (2008).

This study provides further empirical evidence relating to research RCAs and economic growth, with a view to enhancing our understanding of the relationship between research output and economic production.

The most important issues for any country's science policy are research priorities and the efficacy of R&D investment and its relation to GDP. The results here can serve as useful data for less-developed countries when deciding how to direct their investment: toward education, infrastructure and engineering, or more toward fundamental science.

Table 1. GDP growth rate

	Mean				Median	Maximum	Minimum	Std. Dev.
	1982-2007	1982-1990	1991-2000	2001-2007				
Group1								
AUSTRIA	7.2909%	11.0626%	1.8638%	10.1947%	4.6987%	41.8957%	-11.5730%	12.0612%
BELGIUM	6.5304%	8.8719%	1.7050%	10.4134%	4.3940%	38.6257%	-12.0222%	12.2317%
BRAZIL	9.6434%	13.6456%	3.8991%	12.7039%	10.0919%	58.7452%	-31.8767%	19.4624%
DENMARK	7.0691%	10.3461%	1.9683%	10.1425%	5.3760%	41.1117%	-7.9692%	11.5736%
FINLAND	6.9425%	12.1259%	-0.3984%	10.7651%	5.6808%	30.9295%	-21.0726%	12.9913%
FRANCE	6.3201%	9.2638%	0.9341%	10.2297%	4.6119%	38.9573%	-9.4338%	11.5353%
GERMANY	6.9011%	10.3807%	2.6192%	8.5441%	3.0997%	42.8245%	-11.3191%	12.6886%
ITALY	7.1012%	12.6042%	0.0888%	10.0436%	4.3702%	41.6318%	-19.5962%	12.2904%
SPAIN	8.6725%	12.4138%	1.5175%	14.0837%	7.9835%	38.3672%	-15.9975%	13.0909%
SWEDEN	6.0391%	9.0026%	0.7273%	9.8172%	5.4565%	32.3510%	-24.3791%	12.5078%
SWITZERLAND	6.3982%	11.1160%	0.8064%	8.3209%	2.8274%	43.3500%	-13.1804%	12.0919%
average	7.1735%	10.9848%	1.4301%	10.4781%				
Group 2								
AUSTRALIA	6.8905%	6.7702%	2.2862%	13.6226%	6.6791%	27.3682%	-11.3849%	10.7671%
CANADA	6.3479%	7.7613%	2.2944%	10.3213%	4.3040%	18.1791%	-3.2543%	6.3997%
ISRAEL	8.1124%	10.1740%	8.7318%	4.5769%	7.8189%	23.7215%	-8.1675%	9.0553%
NETHERLANDS	7.1235%	8.8300%	3.0038%	10.8149%	4.4567%	39.3659%	-7.4366%	11.3286%
NORWAY	7.5477%	7.5453%	3.8927%	12.7722%	6.5209%	20.1472%	-7.9151%	8.1994%
UK	7.0826%	8.4115%	3.9959%	9.7837%	6.7422%	23.0618%	-10.5329%	9.1087%
US	5.9659%	7.1243%	5.5502%	5.0704%	5.9311%	11.2127%	3.3027%	1.6994%
average	7.0101%	8.0881%	4.2507%	9.5660%				
Group 3								
SINGAPORE	10.5853%	12.0919%	9.7927%	9.7804%	12.3620%	23.6587%	-14.3843%	9.7494%
KOREA	11.6614%	16.1232%	8.5506%	10.3690%	12.4018%	33.9906%	-32.8290%	12.8393%
TAIWAN	8.6978%	14.8290%	7.2577%	2.8720%	8.7109%	33.1616%	-9.9573%	9.2584%
average	10.3148%	14.3480%	8.5337%	7.6738%				
Group 4								
CHINA	13.2861%	11.6457%	12.3919%	16.6728%	10.9568%	67.0636%	-13.5233%	15.3311%
INDIA	7.2869%	5.8102%	4.2127%	13.5774%	7.3241%	26.8286%	-11.2190%	7.7014%
JAPAN	5.9023%	12.1171%	4.9124%	-0.6740%	6.9454%	48.1680%	-12.2543%	12.8361%
POLAND	8.8705%	2.1806%	11.2624%	14.0549%	9.4408%	34.1541%	-13.5225%	11.5137%
average	8.8365%	7.9384%	8.1949%	10.9078%				

Table 2. Publications growth

	Mean				Median	Maximum	Minimum	Std. Dev.
	1982-2007	1982-1990	1991-2000	2001-2007				
Group 1 AUSTRIA	17.3602%	32.6107%	10.4822%	7.5781%	10.7417%	98.7467%	6.5903%	19.3507%
BELGIUM	17.4731%	33.4665%	10.2369%	7.2474%	10.7968%	105.1597%	6.5669%	20.5006%
BRAZIL	20.7839%	35.9470%	13.5318%	11.6486%	13.4404%	113.9013%	10.5092%	21.2918%
DENMARK	16.9404%	32.9903%	9.7803%	6.5337%	10.3102%	103.3435%	5.8632%	20.3693%
FINLAND	18.3503%	35.7190%	10.6503%	7.0190%	11.2665%	114.2911%	5.9997%	22.5442%
FRANCE	16.9406%	33.3756%	9.7508%	6.0811%	10.4475%	103.6514%	5.2400%	20.4921%
GERMANY	16.7185%	33.1838%	9.2767%	6.1802%	9.5629%	105.0006%	5.3453%	20.7895%
ITALY	18.8775%	35.8444%	11.4471%	7.6778%	12.2287%	108.7227%	6.9506%	21.3803%
SPAIN	21.7315%	40.0023%	13.9303%	9.3852%	14.5570%	116.0635%	8.5113%	22.5308%
SWEDEN	17.5099%	35.1329%	9.5526%	6.2192%	10.0367%	111.2454%	5.4283%	22.1188%
SWITZERLAND	17.1683%	33.2235%	10.0048%	6.7594%	10.5921%	104.6570%	6.2805%	20.6707%
average	18.1686%	34.6815%	10.7858%	7.4845%				
Group 2 AUSTRALIA	16.9782%	32.7793%	9.7702%	6.9597%	10.3979%	100.2337%	6.5256%	19.7838%
CANADA	16.9293%	34.4839%	8.8991%	5.8307%	9.6301%	104.5504%	5.5120%	21.0984%
ISRAEL	17.0245%	34.3587%	9.0989%	6.0600%	9.7161%	110.6400%	5.1936%	21.9583%
NETHERLANDS	18.2898%	35.8360%	10.5738%	6.7531%	11.3884%	105.5133%	6.0984%	21.1506%
NORWAY	17.4365%	33.9918%	9.8067%	7.0507%	10.4707%	109.3909%	6.6376%	21.5150%
UK	16.6212%	33.1910%	9.2256%	5.8825%	9.8605%	104.2206%	5.3075%	20.7976%
US	16.1983%	33.2481%	8.4712%	5.3158%	9.1994%	105.0784%	0.047927	21.1088%
average	17.0683%	33.9841%	9.4065%	6.2646%				
Group 3 SINGAPORE	26.3523%	44.9326%	18.1729%	14.1480%	18.6503%	112.4378%	11.1877%	21.9866%
KOREA	31.9686%	49.6976%	26.2971%	17.2764%	26.2896%	131.6456%	12.9425%	23.4360%
TAIWAN	26.5859%	44.8823%	20.1848%	12.2062%	22.7207%	117.3184%	11.1848%	21.6335%
average	28.3023%	46.5042%	21.5516%	14.5435%				
Group 4 CHINA	0.285791	51.3089%	16.2457%	16.9743%	17.6974%	176.2849%	14.3646%	32.5374%
INDIA	15.4608%	30.7925%	7.9707%	6.4487%	8.2494%	97.0941%	5.8635%	19.2570%
JAPAN	17.6090%	34.2095%	10.5239%	6.3870%	11.0916%	99.9457%	5.1110%	19.9354%
POLAND	16.4406%	30.8929%	9.4596%	7.8318%	9.6381%	76.9776%	6.5201%	16.3441%
average	19.5224%	36.8010%	11.0500%	9.4105%				

Table 3. Correlation coefficients of GDP and publications

Group 1		Group 2		Group 3		Group 4	
Austria	0.9247	Australia	0.9275	Singapore	0.9247	China	0.9952
Brazil	0.8131	Canada	0.9245	South Korea	0.9193	India	0.9120
Belgium	0.9349	Israel	0.9786	Taiwan	0.8768	Japan	0.7772
Denmark	0.9480	Netherlands	0.9636			Poland	0.9498
Finland	0.9080	Norway	0.9507				
France	0.9307	UK	0.9701				
Germany	0.9045	US	0.9955				
Italy	0.9137						
Spain	0.9432						
Sweden	0.9071						
Switzerland	0.9180						

Table 4. Granger causality results

Country	GDP	Publication	Co-integration test	Publication →gdp $\chi^2$ statistics	Gdp→ Publication $\chi^2$ statistics	lag
Austria	I(1)	I(2)		13.0270 *	2.4698	7
				(0.0715)	(0.9294)	
Belgium	I(1)	I(2)		0.0015	0.9227	1
				(0.9687)	(0.3368)	
Brazil	I(1)	I(2)		20.0515 ***	18.1430 **	7
				(0.0055)	(0.0113)	
Denmark	I(1)	I(1)		0.9081	2.0254	2
				(0.6351)	(0.3632)	
Finland	I(1)	I(1)		1.3914	2.1326	2
				(0.4987)	(0.3443)	
France	I(1)	I(2)		0.0638	0.1402	1
				(0.8006)	(0.7080)	
Germany	I(1)	I(2)		15.2330 **	1.8531	7
				(0.0331)	(0.9675)	
Italy	I(1)	I(1)		3.1164	15.8586 **	7
				(0.8740)	(0.0264)	
Spain	I(2)	I(2)		102285	15.3503 **	7
				(0.9903)	(0.0318)	
Sweden	I(1)	I(1)		4.7812	1.9957	8
				(0.7807)	(0.9811)	
Switzerland	I(1)	I(2)		7.3074	2.5712	7
				(0.3976)	(0.9216)	
Australia	I(2)	I(2)		11.8655 **	3.4228	4
				(0.0184)	(0.4897)	
Canada	I(2)	I(2)		8.3542	3.4705	7
				(0.3024)	(0.8383)	
Israel	I(1)	I(2)		5.8492	25.3172 ***	7
				(0.5575)	(0.0007)	
Netherlands	I(1)	I(1)		25.6657 ***	5.3227	6
				(0.0003)	(0.5031)	
Norway	I(2)	I(2)		1.7151	14.6747 **	7
				(0.9739)	(0.0404)	
UK	I(2)	I(1)		2.3811	9.3219	7
				(0.9358)	(0.2304)	
US	I(1)	I(2)		6.8258	17.4291 ***	6

(0.3373)

(0.0078)

Table 4. Granger causality results (cont)

Country	GDP	Publication	Cointegration test	Publication →gdp $\chi^2$ statistics	Gdp→ Publication $\chi^2$ statistics	lag
Singapore	I(1)	I(1)		26.2357 *** (0.0005)	40.8119 *** (0.0000)	7
south Korea	I(1)	I(0)		402.3405 *** (0.0000)	82.1670 *** (0.0000)	8
Taiwan	I(1)	I(1)		53.9524 *** (0.0000)	53.7584 *** (0.0000)	6
China	I(2)	I(3)		4.8986 (0.6723)	16.3316 ** (0.0223)	7
India	I(2)	I(2)		55.7718 *** (0.0000)	4.5068 (0.6084)	6
Japan	I(1)	I(0)		683.9565 *** (0.0251)	47.8411 *** (0.0722)	8
Poland	I(2)	I(2)		9.1676 (0.2408)	6.9019 (0.4392)	7

Notes: p values in parentheses; \* co-integration significant at the < 10% level, \*\* significant at the < 5% level, \*\*\* significant at the < 1% level.

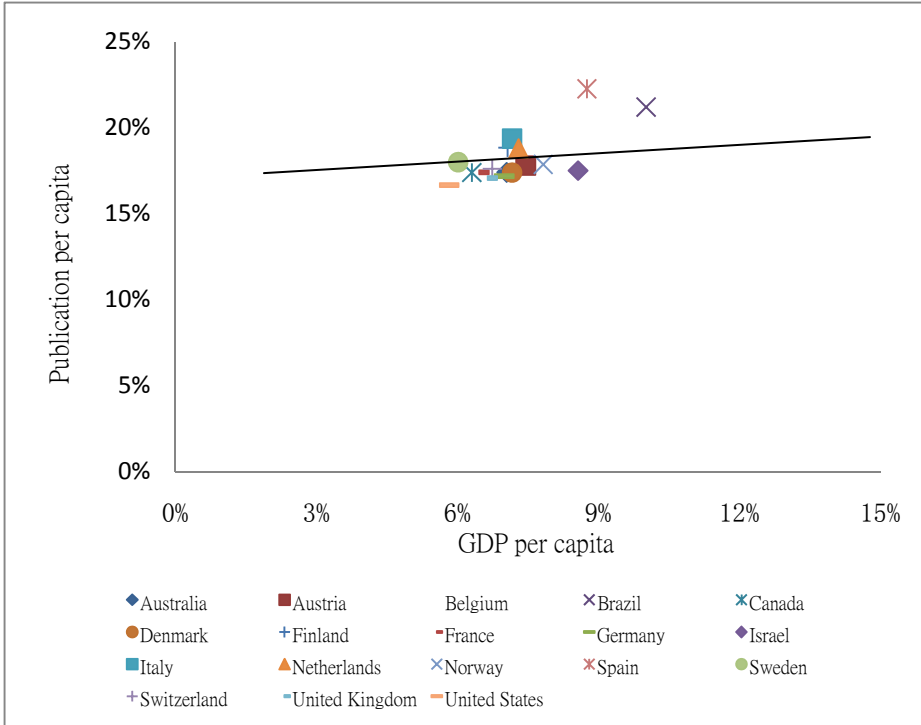


Figure 1. Economic productivity and research output in Group 1 & Group 2 countries

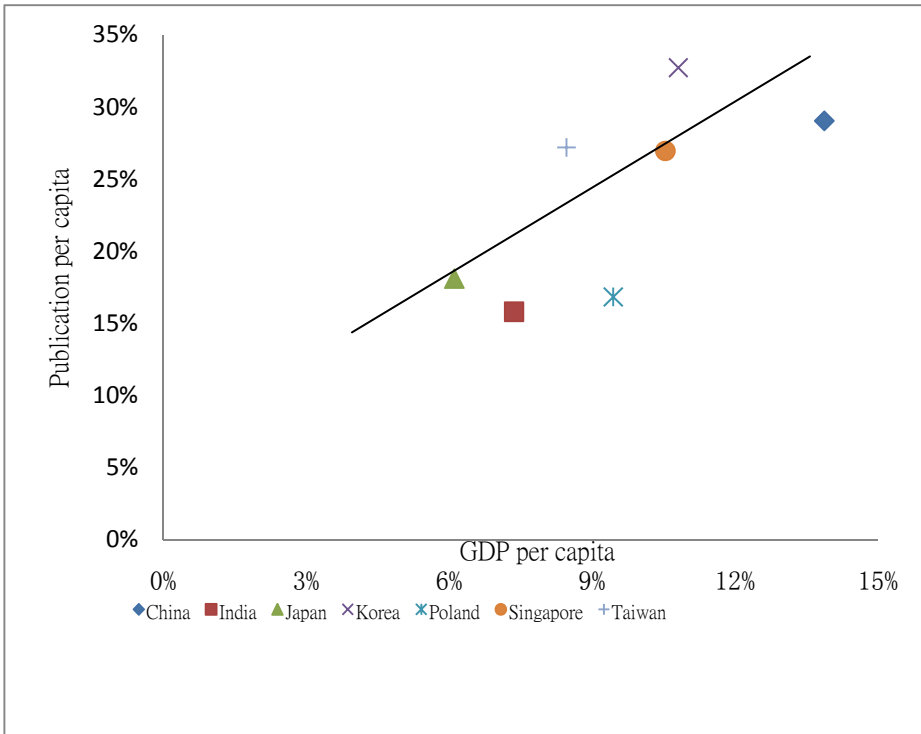


Figure 2. Economic productivity and research output in Group 3 & Group 4 countries