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Research and Development. The Role of Universities for the Knowledge-based Society and Technological Innovations

Expenditure in Scientific Research and Applications as Crucial Factors for Economic Growth and the New Technological Frontiers

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Abstract. Research and Development (R&D) has been proved to be crucial factor moving the world technological frontiers, while at the same time facilitating new technological and scientific innovations. Investing in research by state and private institutions and industrial enterprises, as well as applications of advanced technology in the various sections of the economy, has been proved to play a significant role in the economic growth and prosperity of a country. R&D comprise of creative work undertaken on a systematic basis in order to increase the stock of knowledge in various fields of science and technology and advance education, learning and expertise in the country's manpower. In the last decades international knowledge, in natural sciences, social and economic fields, flows continuously and studies showed that is a major factor in world economic growth. Universities are an increasingly important component of the scientific innovation and technological advances in many sectors of the economy and production.

The role of R&D is evidenced by the recent scientific literature on the impact of science and technology spillovers on growth and productivity of developed and developing countries. Expenditure in scientific research and technological development in most countries provided a set of indicators that reflect the increased economic progress and the advanced technological structure at national level. Appropriate use of R&D provide solutions to infrastructure systems (motorways, transport facilities, energy storage and electricity grids, telecommunications, sewers, naval ports, environmental protection facilities, etc) serving the economy, industry, and agriculture on a global scale. This review provides a comprehensive outlook, statistical data and important research papers on the levels of R&D expenditure in various developed countries (US, China, Germany, UK, Japan, Greece) and the competitive edge that provides in the introduction of new technological discoveries and innovation in economic fields, increase growth at national and international levels, productivity, advance knowledge and expertise among manpower.

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1. Introduction: Research and Development and Economic Growth

Economic theory points to the fact that the process of industrial revolution and technological changes in the last century proved to be major sources of productivity growth in developed and developing countries in the long run. New technological processes allowed industrial enterprises, units of primary production (raw materials, industrial engines, energy, agriculture, fisheries, etc) and services to increase output per worker or per unit of capital. Applications of technological change in transport, housing, energy, telecommunications, new consumer products and food contributed to improving the well-being of citizens, workers and consumers. Research and Development (R&D) has been proved to be crucial factor moving the world technological frontiers and facilitated new technological and scientific innovations. Sustained and significant economic growth in develop0ed and developing countries per capita income started roughly with the first era of the industrial revolution. There is little doubt that technological progress through industrial innovations played the key role in initiating, accelerating, and sustaining economic growth in the modern era, especially after the Second World War in North American and European countries.[1-4]

Innovation in the primary, secondary and service sectors and extensive application of new technological methods that have been invented through vigorous R&D can make economic growth sustainable and durable. Especially information technology over the 1990s, has substantially contributed to recent improvement in the productivity of enterprises, industrial production and services. The existing scientific literature on more ‘aggregated’ economic analysis pointed to R&D as being the ultimate source of technological change. Most studies in this field of research have confirmed that domestic business R&D and foreign R&D are major drivers of economic growth. A number of studies have also provided evidence about the economic effect of research in state institutions and private enterprises. There is strong statistical macroeconomic evidence of the simultaneous impact of business R&D, foreign R&D and public R&D on economic growth of developed and developing countries.[5,6]

After the initial stages of industrial revolution in selected countries, new applications of scientific discoveries took place to solve practical problems. The goals were to increase productivity, improve properties of materials, increase quality of life, improve health, sanitation, etc. Scientific and technological advances were based on research and prior discoveries, methods and application and new knowledge were disseminated, refined and revised through additional experimentation. Many crucial discoveries brought substantial economic growth and wealth to industrial countries. Some of the most important technological innovations and discoveries as a result of R&D in the last 150 years were: electricity (1873), light bulb (1850-1878) telephone (1876), radio (1897), automobile (1886), X-rays (1895), Quantum physics (1900), airplane (1903), refrigeration (1913), television (1926), penicillin (1928), atomic bomb (1945), computer (1946), the structure of DNA (1953), microprocessor (1971), internet (1991), the integrated circuit (1959), mobile phone (1973). These of course are the most important discoveries which changed the industrial civilization and improved human life in the modern era.[7]

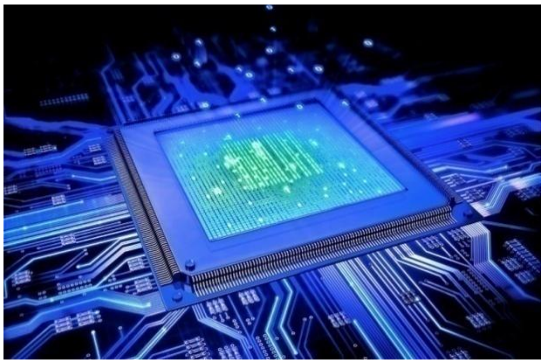



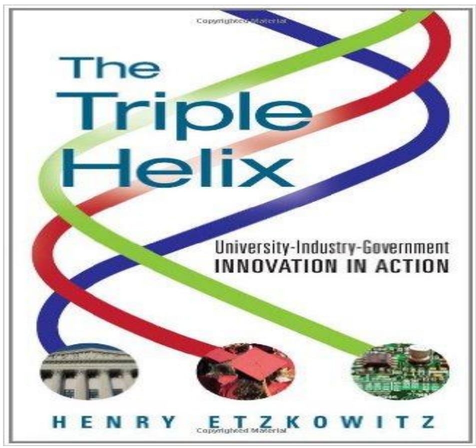
Figure 1. Electricity and electric power distribution in the 1880s were the most important innovations after the industrial revolution. A computer processor was another technological revolution. It incorporated the functions of a computer's central processing unit on a single integrated circuit or few integrated circuits.

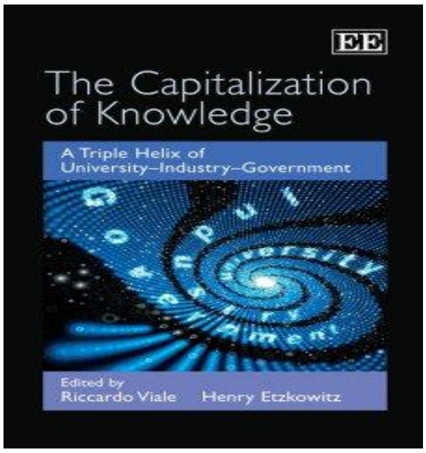
In 2015 the Scientific American asked some scientists which are the 10 top emerging technologies in 2015, and the answers were: Fuel-cell vehicles, next-generation robotics, recyclable thermoset plastics, precise-genetic engineering techniques, emerging artificial intelligence, distributed manufacturing (factory on line), additive manufacturing (printable organs, 3D products, intelligent clothing), neuromorphic technology (computer chips that mimic human brain) and digital genome (health care).[8]

2. The "Triple Helix" Institutions in a Knowledge-based Society for Research Innovation and Development

Research & Development by scientific institutions (public research laboratories and universities) and private industrial enterprises comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge in various fields of science and technology and advance education, learning and expertise in the country's manpower. All these functions are important sources in modern, industrial economies for improved economic performance through the ability to absorb new technologies coming out of domestic and foreign R&D. Although the relationship between R&D and innovation is complex and nonlinear, it is clear that substantial advances in technology cannot occur without scientific work being undertaken on a systematic basis. R&D performed by private business results in new goods and services, in higher quality of output, in higher productivity, lower prices of consumer products, new production processes and sources of economic growth at the macroeconomic level. Investigations in many developed countries (especially in the USA and the European Union countries) showed that R&D does matter in economic growth, labour productivity, and "social" return, for the long-term effects on the prosperity of the country. Cross-national spillover effects of government and private investment in R&D (data set of ten OECD countries) showed that domestic private research is a significant determinant of both domestic and foreign productivity growth.[9-11]

Government and university R&D have a direct effect on scientific, basic knowledge and on public missions. Basic research performed mainly by universities enhances the stock of knowledge available for the society. New knowledge is not considered as an output in the current system of national accounts (contrary to new equipment and software for instance), and as such it is not included in GDP measures; hence the direct outcome of basic research is overlooked. However, basic research may open new opportunities to business research, which in turn might improve productivity. Social and economic research in the last decades, established technological innovation is increasingly based upon a "Triple Helix" of university-industry-government interactions.[12-14]





F**igure 2**. Etzkowitz H. *The Triple Helix. University-Industry Government Innovation in Action* . Routledge publs, New York, 2008. Viale R, Etzkowitz H (Eds). *The Capitalization of Knowledge. A Triple Helix of University-Industry-Government*. EE Edward Elgar, Cheltenham, Glos, UK, 2010.

Institutional research leading to technological discoveries is based on new knowledge and the role of the university is very crucial. Basic research and fundamental technological progects m in university laboratories play an important role in the incubation of technology-based enterprises. The entrepreneurial university takes a proactive stance in putting knowledge to use and in broadening the input into the creation of academic knowledge. In this respect the university operates according to an interactive rather than a linear model of innovation. As industrial enterprises raise their technological level in the pursuit of innovative products, they move closer to an academic model, engaging in higher levels of training and in sharing of knowledge. Government acts as a public entrepreneur and venture capitalist in addition to its traditional regulatory role in setting the rules of the game.

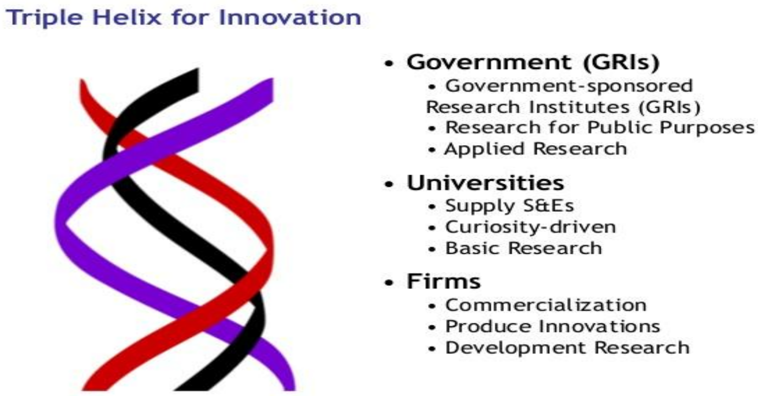


Figure 3. The concept of Triple Helix innovation of university-industry-government relationships initiated in the 1990s by Etzkowitz and Leydesdorff. The concept interprets the shift from a dominating industry-government dyad to a growing relationship between university-industry-government in the knowledge-based society, with rigorous economic development, transfer and application of innovation and technological discoveries.

Moving beyond product development, innovation then becomes endogenous process which encourage hybridization among the institutional spheres. In the last two decades there is a fundamental transformation of the universities as teaching institutions into a combination of teaching with research, a process that is not only obvious in the USA, but in many other developed countries. It is considered as a second academic revolution. Intellectual capital is becoming as important as financial capital as a basis of future economic growth. The development of an entrepreneurial academic ethos that combines an interest in fundamental discovery with technological application, emerges as an influential actor and equal partner in a

"Triple-Helix", improving conditions for innovation in knowledge-based society. Industry operates as a locus of production (machines, consumer products, electronic instruments, etc) government operates as a source of contractual relations that guarantee stable interactions and universities operate as a source of new knowledge and technological discoveries.[15-17]

In the last two decades universities around the world are increasingly shifting from their traditional primary role as educational providers and scientific knowledge creators to a more complex "entrepreneurial" university model that incorporates the additional role of the commercialization of knowledge and active contribution to the development of private enterprises in the local and regional economy. As a result, universities become an increasingly important component of the national innovation system.[18-20]

3. Gross Domestic Spending on Research and Development (R&D) in Developed Countries

Gross domestic spending on Research and Development (R&D) is defined as the total expenditure (current and capital) on R&D carried out by all resident companies, research institutes, university and government laboratories, etc., in a country. It includes R&D funded from abroad, but excludes domestic funds for R&D performed outside the domestic economy. This indicator is measured in million US$ and as percentage of GDP (Gross Domestic Product).[21]

Eurostat in the EU devotes a special section where Statistics are Explained for R&D Expenditure. [http://ec.europa.eu/eurostat/statistics-explained/index.php/R_%26_D_expenditure]. Eurostat uses data that are obtained through statistical surveys which are regularly conducted at national level covering R&D performing entities in the private and public sectors. The EU during the last decade encouraged the increase of investment in R&D, in order to provide a stimulus to the EU's competitiveness in the economic sectors (industry, agriculture and services). The objective of the EU countries was to devote 3% of their GDP for R&D activities by 2010. The target was not reached by many countries (e.g. Greece, below 1% of GDP) and subsequently the 3% target formed one of five key targets within the Europe 2020 strategy.

The Gross domestic expenditure in R&D (GDE-RD) (public and private sectors) for the 28 countries of the EU stood at 272 billion in 2013, which was 43% higher than 2003. In 2012, the level of expenditure on R&D in the EU-28 was equivalent to 75% of that recorded by the USA. Other countries that are in competition with the EU economies have higher expenditure for R&D. For example, Japan and South Korea expenditure for R&D was 3.5% and 4.2 % respectively of the GDP of these countries in 2014.[22]

In the last decade China's economy is advancing by 8-10% annually and it is estimated that by 2018, China's contribution to global GDP will surpass that of the USA. In the same period China's R&D intensity increased rapidly, rising from 1.13% in 2003 to 1.98% in 2012, an increase of 85%. Among the EU member states, the highest R&D intensities in 2013 were recorded in Finland (3.31%), Sweden (3.3%) and Denmark (3%). Also, there were 10 member states that reported R&D expenditure that was below 1% of their GDP in 2013 (Greece, and the countries that joined the EU in 2004 or more recently).[22]

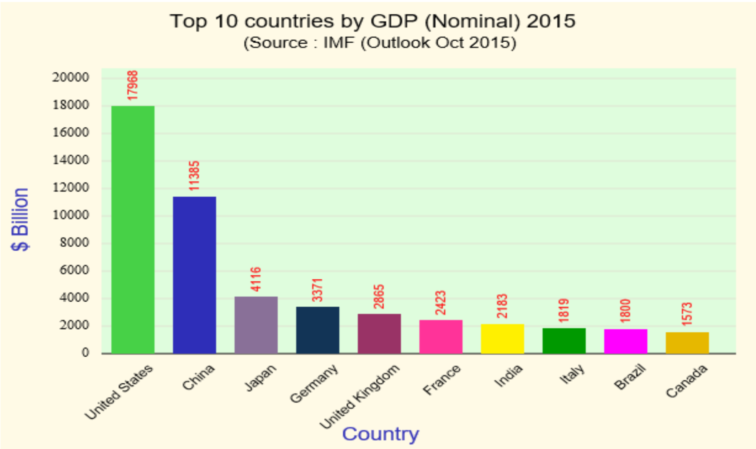


Figure 4. Although US is leading the Gross Domestic Product (GDP) list of the world's largest economies, China is advancing on yearly growth with 6-8% rising to the top of GDP list by 2020, The US has been a global leader since overtaking the United Kingdom in 1872.

In November 2011, the European Commission presented a successor for the 7th framework programme by announcing Horizon 2020, a programme for investing nearly EUR 80 billion (**€**) in research and innovation, implementing the goal of EU for R&D. Horizon 2020 focuses on turning scientific breakthroughs into innovative goods and services that have the potential to provide business opportunities, increase employment and change people's lives for the better. Running from 2014 to 2020 this programme is part of the EU's drive to create new growth and jobs in the European countries.[22,23]

The Organization of Economic Development and Co-operation (OECD, Paris), is an intergovernmental economic organisation with 35 member countries, founded in 1961. The countries in the OECD are the most developed industrial economies on Earth. OECD collects data on R&D expenditure and science and technology indicators. Data are: Semiannual, DOI: 10.1787/data-00182-en, Years covered: 1981-2012. Main Science and Technology provides a set of indicators that reflect the **level** and structure of the efforts undertaken by OECD Member countries. According the OECD and other statistical data the world's expenditure on R&D was approximately one trillion dollars (US$) in 2010 and now (2015) is at 1.7 trillions.[24,25]

Table 1. OECD, 2016, Gross domestic spending (GDS) % on Research and Development (R&D) for selected developed countries doi: 10.1787/d8b068b4-en.
The world's total nominal R&D spending was approximately one trillion dollars in 2010 [http://royalsociety.org/uploadedFiles/Royal_Society_Content/Influencing_Policy/Reports/2011-03-28-Knowledge-networks-nations.pdf]. (accessed October 2016)
R&D -- Gross domestic spending on R&D - OECD Data". data.oecd.org. (retrieved 2016) [http://www.stats.gov.cn/tjsj/sjjd201605/ t20160531_1362661.html].

Countries	**Year 2002 of GDP**	**2010**	**2012**	Expenditure R&D, billions US$ PPP and as % of GDP
Australia	2.25%	2.2%	2.1%	23.3 billions, 2.12% (2014)
Belgium	1.89	2.05	2.93	11.9 billions, 2.46%, (2014)
France	2.7	2.18	2.23	58.4 billions, 2.25% (2014)
Germany	2.42	2.71	2.87	106.5 billions, 2.84 (2014)
United Kingdom (UK)	1.72	1.74	1.62	43.7 billions, 1.70 (2014)
United States	2.55	2.74	2.70	473.4 billions, 2.74% (2013) 514 billions (2016)
Israel	4.13	4.1	4.13	11.2 billions, 4.1% (2014)
Japan	3.12	3.25	3.58	170.8 billions, 3.58% (2014)
South Korea	2.27	3.47	4.03	91.6 billions, 4.29%, (2014)
European Union of 28 countries	1.71	1.84	1.92	334.3 billions, 1.94%, (2014)
Russia	1.25	1.73	1.13	42.6 billions, 1.18%, (2014)
China	1.06	1.73	1.93	409 billions, 2.2%, (2014)
India	0.5	0.7	0.8	66.5 billions, 0.85%, (2013)
Greece	0.55	0.76	0.8	1.48 billions, 0.84% (2014)

PPP. Purchasing power parity. The concept of PPP allows one to estimate what the exchange rate between two currencies would have to be in order for the exchange to be at par with the purchasing power.

The forecast for the top list of countries with R&D expenditure per year in 2016 and as % of GDP were published in the R&D Magazine (www.rdmag.com).[26]

Table 2. Forecast for 2016, for the Gross Domestic Product (GDP) of the 10 top developed countries, the % of expenditure for R&D and total expenditure (forecast)

Countries	**GDP (2016 forecast) trillions of US$**	**% GDP for R&D**	**Total expenditure billions US$ for R&D (2016)**
USA	18.5 trillion of US$ (25% of global GDP)	2,77 %	514 billions of US$
China	11.3 (2016) (15% of global GDP)	1,96 %	396
Japan	4.9	3,4 %	166
Germany	3.7	2,92 %	109
India	8.4	0,85%	71
France	2.6	2,26 %	60
UK	2.5	1,78 %	45
Russia	3.4	1,5 %	50
South Korea	8.4	4,0 %	77
Italy	2.09	1,27 %	26,6

****Forecasts for 2020. GDP of China is expected to reach 20.85 trillion US$ while USA will remain the same at 18.5 trillion, India 8.4 trillion US$ and Japan 5 trillion US$.**

The USA continues to remain on the top of investing in research and technological innovations, despite the slowing down in the last years, but China is advancing recently, by increasing substantially its expenditure for R&D. At present the U.S. R&D investment is 25% of all global spending. U.S. scientists publish the highest proportion of scientific papers in high impact factor journals with the highest citation index. R&D total investment in the U.S. is supported by the industrial sector (66%), by federal government (25%) and by academic/non-profit institutions (7%).[25]

There are substantial changes of the U.S.'s industrial R&D makeup. Life science R&D, for more than 10 years, has been the largest sector in the industrial technology arena. For 2016, many of the large players in this sector—Novartis, Pfizer, Merck, Sanofi, Astra Zeneca, Eli Lilly, GlaxoSmithKline (most have large U.S. industrial installations)—are expected to reduce their large multi-billion dollar annual R&D investments. Some pharmaceutical companies in recent years had reduced revenues and a reduced ability to continue funding mega-scale R&D programmes. In other industrial areas, most global automotive companies (except for Volkswagen, the largest global company with the largest total R&D expenditure) are expected to grow their R&D programs due to strong technology shifts from internal combustion to electric propulsion, automated driving systems and integrated electronic systems.[25,26]

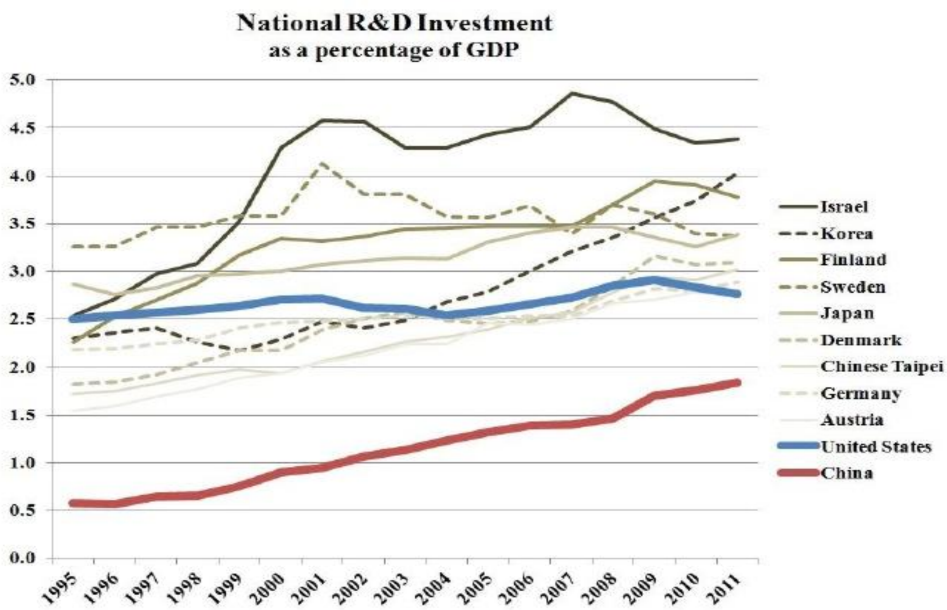


Figure 5. The U.S. is failing to keep pace with competitors' investments in R&D. As China's R&D intensity (red line) rapidly grows at an average of 6-8% per year in pursuit of the globally-recognized 3% GDP goal, U.S. investments (blue line) have pulled back. At this pace, China will surpass the U.S. *Data Source: OECD, Main Science and Technology Indicators, 2013, Gross Domestic Expenditures on R&D as a percentage of GDP. Available at: http://stats.oecd.org/.* Lane NF. Investments in basic research are just that, investments. *Scientific American* 22.7.2014.

All statistical evidence showed that the U.S. is failing to keep pace with competitors' investments in R&D especially with China. **The** U.S. expenditure is at 2.7% of GDP and ranks 10th in national R&D investment as a % of GDP, or R&D intensity (annual increased to R&D spending). China's R&D intensity (red line) rapidly grows at an average of 6-8% per year, while U.S. investments (blue line) have pulled back. China has the world's largest pool of human resources for science and technology, but the qualified scientists and technologists as a percentage of population remains extremely low. China lacks world-class researchers, compared to the U.S. and West Europe countries. For instance, the US is home to 35 of the world's top 50 universities and accounts for 26% of world articles in science and engineering. The universities of European Union also are on the top list and their research activities and scientific publications are high quality with very high citation index. Chinese universities awarded over 27,000 doctorates (science and engineering, 2011) with U.S. universities (24,792).[27]

Innofund program was a special government R&D program established upon the approval of the State Council in May 1999. Innofund was aiming to "*facilitate and encourage the innovation activities of small and medium technology-based enterprises (SMTEs) and commercialization of research by way of financing, trying to bring along and attract outside financing for corporate R&D investment of SMTEs*." China's Innofund was providing three forms of financing, namely, appropriation, interest-free bank loans, and equity investment. Appropriation was provided as start-up capital for small firms founded by a researcher with scientific achievements. Partial subsidies are also provided to SMEs for the development of new products and pilot production. From 1999 to 2011, Innofund provided more than 19,17 billion RMB to 30,537 projects, 27,498 (86%) of which were supported through appropriation, 2880 through interest-free loans, and 1159 through other forms, including bank loan insurance, equity investment, and other forms of subsidies. The size of direct investments by Innofund appears to be modest compared with the total expenditure for government R&D in China [1 USD$ =6.7 Chinese Yuan Renminbi (RMB)]. Since 1999, the program has created approximately 450,000 new jobs and generated 209.2 billion RMB in sales, 22.5 billion RMB in tax income, and 3.4 billion RMB in exports. By the end of 2008, 82 out of 273 publicly listed companies in China's SME Stock Exchange were once supported by Innofund.[28]

The Gross domestic expenditure (GDE) in the industrial countries in the period after 1995 was increasing at a rate of 2-3% every year, but as is shown In Figure 5 the GDE-R&D rate is slowing down in the USA and EU countries with the exception of China in which R&D increased with steeper growth. [29]

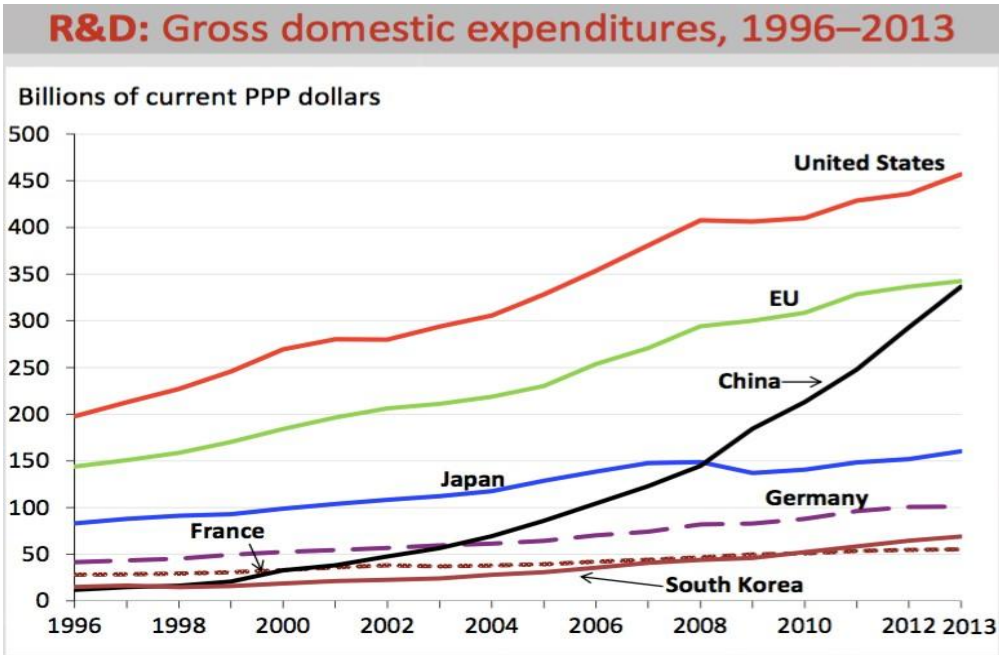


Figure 6. The range of Gross Domestic Expenditure in the period 1996-2013 increased substantially in China, South Korea and Germany. Increase of R&D expenditure. The U.S. remains the world leader, with 28% of the $1.7 trillion spent on R&D globally (2013). China with 20% of the total R&D, is second in the world.[29]

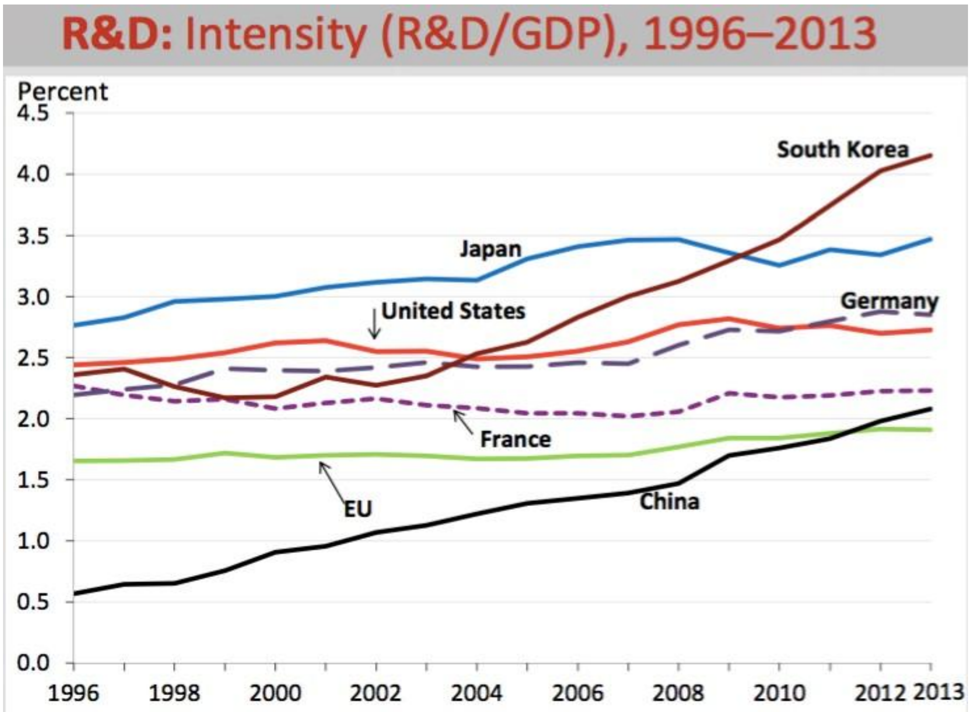


Figure 7. The rise of China, India, and South Korea is taking place against the backdrop of a lack of growth in U.S. research intensity – a measure of R&D expenditure as a percentage of the GDP. The U.S. has fallen from first to eleventh place in R&D intensity, which puts the nation behind many European countries, Japan, South Korea, and Israel.[29]

4. What Drives R&D Intensity Rates in Developed Countries? The Role of Universities

Many studies in the last decade investigated the drives of R&D intensity (% yearly increases for long periods) in developed countries, especially the OECD countries which are among the most industrialized and entrepreneurial in scientific innovations and technological discoveries. A study investigated (2007) the potential determinants of business-sector R&D intensity expenditures (in OECD countries for the period of 1975–2002). Estimates showed a high degree of tax incentives for R&D have a significant and positive impact on business R&D spending regardless of the specification. Also, the study observed that universities' expenditure for R&D are significantly positively related to business enterprise sector expenditures on R&D, indicating that public sector R&D and private R&D are complementary. Direct R&D subsidies and the high-tech export share are significantly positively related to business-sector R&D intensity. Also, countries characterised by strong patent rights appear to have higher R&D expenditure intensities.[30]

Universities in developed countries have been the subject of research for their R&D expenditure by quite large number of researchers since 1980s. Most of their work focused on the university–industry technology transmission mechanism using firm or industry level data. In the USA the Bayh-Dole Act of 1980 gave universities the right to patent inventions resulting from federally funded research. The result was a large increase in patents, and in licensing of university patents. The Economic Recovery Tax Act in the U.S. of 1981 extended the R&D tax credit to company-financed academic research, thereby promoting company support for universities. The Small Business Innovation Research Act of 1982 (U.S. SBIR) intended to help small businesses conduct research and development (R&D). Funding takes the form of contracts or grants. The recipient projects must have the potential for commercialization and must meet specific U.S. Government R&D needs. The SBIR program was created to support scientific excellence and technological innovation through the investment of federal research funds. In 2010, the SBIR programme run across 11 federal agencies and provided over US$ 2 billion in grants and contracts to small U.S. businesses for research in innovation leading to commercialization. The programme required to put aside funds to support start-ups, including some headed by university researchers. The rewards from university research traditionally come from reputation but also from the financial incentives. Reputation in universities promotes mobility which in turn generates salary increases in researchers-professors. Also, the rewards from R&D to academic research depend on the dissemination of findings and open science (publications, conferences, financial support). But the rewards to industrial research derive mostly from corporate profits, and these rely on confidentiality. Hence the coming together of academic and industrial research moves academic research towards secrecy, in conflict with standard academic practice.[31,32]

Academic science and industrial research as well technology transfer from the laboratories to the industrial sector in USA, Japan, United Kingdom (UK) and other developed countries is the result of stronger links between higher education institutions (universities and technological and research institutes) with industrial enterprises that use technological innovations for applications in the production of their products.[33-35]

Studies in the last decade showed that Industry–university cooperation in R&D in most developed countries has been very effective in generating innovation. The interaction facilitates the advancement of knowledge and the advancement of new technologies and in addition has positive effects on both scientific results and economic performance. For industrial firms, universities represent unique sources of knowledge and discoveries, while for academic researchers, the cooperation with industrial companies represents an opportunity to obtain funds for their own research, for equipment, and for research assistants (leading to MSC and PhDs degrees and expertise among young researchers). The expertise among young graduates can lead to opportunities to test practical applications of their theories and start-ups for new business and increased employment.[36,37] There are various benefits derived from industry–university joint research projects. For example, competitive advantages for firms, opportunities for field experimentation, the funding of academics' activities and knowledge and technology transfer among partners. A recent study compared the coordination and control systems implemented in 6 industry–university joint research projects their planning and mutual adjustment practices and incentives. [38]

These strategic relationships university-industry on R&D are a dimension of entrepreneurial activity, and they are thus important drivers of economic growth and development in many countries. Business collaboration with universities increased the efficiency and effectiveness of industrial investments. Studies have found that universities are more likely to collaborate with industry if the business is mature and large, is engaged in exploratory internal R&D, and there are not major intellectual property (IP) issues between both parties. Businesses gain from such collaborations through increased commercialization probabilities and economies of technological scope. A recent study analysed information based on publicly available data collected by the Science-to-Business Marketing Research Centre of Germany, as part of a European Commission project. The study found positive dimension in the relationships to fostering university-business R&D collaborations.[39]

During 2013, 14 EU country reports were published, each presenting aggregate information about the country's state of university-business collaboration as quantified through the S2BMRC survey (Science-to-Business Marketing Research Centre of Germany). Figure 7 (below) showed the results from EU 14 countries from the survey-responses to questions by universities (Higher Education Institutions, HEI*)* indicating to what extend cooperate with business (industry) with respect to collaboration in R&D. Over 3,000 universities participated in the study (responses from 6,280 academic researchers).[40,41]

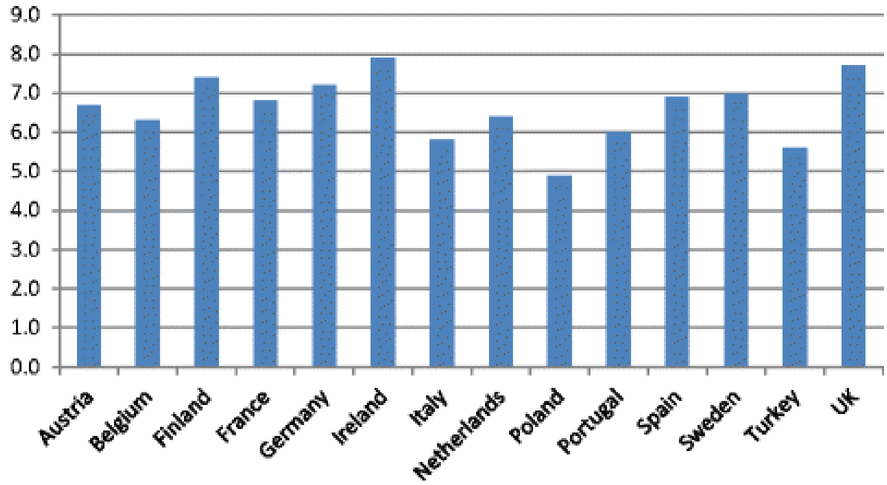


Figure 8. Extent of Industry-Business Collaboration in R&D, by Country. Note: Mean responses from universities (academic researchers), by country, based on a 10-point scale. Response scale: 1 = "Not at all" to 10 = "To a large extent". The highest response was from UK, Ireland, Finland, Sweden and the lowest from Poland.

As we can see from Figure 7, the majority of the responses showed that universities in European Union cooperate with industry in R&D and participate in the development of innovations for technological applications. The scientific bibliography contains in recent years various statistical projects and research papers on the partnerships of universities with industry in research projects for discoveries and explorations of technological innovations.[42-44] Another macro study on higher education R&D and its impact on productivity growth in 17 high-income OECD countries suggest that R&D performed by higher education is positively affecting productivity growth in all specifications. [45]

5. List of Most Innovative U.S. Universities and R&D Expenditure

The U.S. universities have very high budgets of expenditure in R&D. Most of the money for research comes from federal government, local government and businesses. Also, non-profit organizations offer funds for research. Top-ranked Johns Hopkins University in 2012 received most of the R&D funding of 2,1 billions US$ for science and engineering. JHU committed nearly $40 million toward environmental science research in 2012. The top list of universities in the U.S. was:[46]

1. ***Johns Hopkins University.*** *JHU is on the top of the list for expenditure on R&D. Life sciences (particularly biology and medicine) and electrical engineering were the fields that received the most R&D funding. Total R&D expenditure was: US$ 2,106,185 (thousands of dollars) (or 2,1 billion of US$), Science: $1,233,438, Engineering: $859,561. Funding Sources (thousands of dollars): Federal government: $1,857,580, State and local government: $5,109, Institution funds: $80,988, Businesses: $47,102, Nonprofit organ: $114,054, Other donors: $1,352*
2. ***University of Michigan****. The university receives very little funding from state and local government sources, but manages to offset this shortfall with more than $433 million in institution funds; Total R&D Expenditure: US$1,322,711 (thousands of dollars), Science : $1,026,614, Engineering: $221,066, Other: $75,031*
3. ***University of Wisconsin****. Nearly 80% of R&D funding is allocated for scientific fields; life sciences alone comprise more than 50% of the entire R&D expenditure. Total R&D Expenditure: $1,169,779 (thousands of dollars), Science: $916,863,Engineering: $113,742, Other: $139,174*
4. ***University of Washington****. Funding for medical science research represents more than 33% of annual R&D expenditure, while environmental and biological science research comprises more than 25%. Total R&D Expenditure: $1,109,008, (thousands of dollars) Science: $961,218, Engineering: $104,196,Other: $43,594*
5. ***University of California San Diego****. In 2012, UCSD allocated 87.5% of its R&D funding toward scientific studies. Medical sciences-related projects received more than 50% of this amount. Total R&D Expenditure: $1,073,864 (thousands of dollars), Science: $939,199, Engineering: $126,107, Other: $8,558.*
6. ***University of California-San Francisco****. All of the R&D funding at UCSF is allocated to scientific studies. Medical science received the vast majority of these monies (roughly $987 million in 2012). Total R&D Expenditure: $1,032,673 (thousands of dollars), Science: $1,032,673.*
7. ***Duke University.*** *Expenditure of $950 million to R&D studies in biology, medicine, and other life science fields. Engineering research, received less than $60 million for projects related to either electrical or bio/biomedical engineering. Total R&D Expenditure: $1,009,911 (t.o.d), Science:$946,167, Engineering:$58,592.*
8. ***University of California-Los Angeles****. Nearly $900 million of UCLA's 2012 R&D budget was given to researchers in scientific fields; $686 million was allotted for medical research.* Total R&D expenditure*: $1,003,375 (thousands of dollars).*
9. **Stanford University.** The university ranked third among the top 10 schools on our list in terms of R&D expenditure for engineering projects. Total R&D Expenditure: $903,238 (thousands of dollars)**.**
10. **Columbia University in the city of New York**. Life science fields (such as biology and medicine) claiming nearly $600 million. Other fields that received a relatively large amount of funding include physics and electrical engineering.

Total R&D Expenditure: $889,487 (thousands of dollars).

11. **University of North Carolina at Chapel Hill.** Total R&D Expenditure $884,791 (thousands of dollars).
12. **University of Pittsburgh.** Total R&D Expenditure: US$883,791 (t.o.d).
13. **University of Pennsylvania**. Total R&D Expenditure: $847,077 (t.o.d) .
14. **University of Minnesota-**Twin Cities. Total R&D Expenditure: $826,173 (t.o.d).
15. **Massachusetts Institute of Technology (MIT**). Total R&D Expenditure: $824,130 (thousands of dollars).
16. **Cornell University.** Total R&D Expenditure: $802,387 (thousands of dollars).
17. **Harvard University.** Total R&D Expenditure: $799,432 (thousands of dollars).
18. **Pennsylvania State University.** Total R&D Expenditure: $797,679 (t.o.d).
19. **Ohio State University**. Total R&D Expenditure: $766,513 (t.o.d).
20. **University of California-Berkeley**. Total R&D Expenditure: $730,348 (t.o.d).

It is no surprise that famous universities like Harvard, Stanford and MIT are not on the top of the list of the R&D expenditure. Some U.S. universities are very big, like Michigan that has more than 6,000 academic personnel and their research facilities are very diverse. Johns Hopkins for many years has some of the most advanced scientific facilities among U.S. higher education institutions. JHU scientists and engineers operated the first spacecraft to visit Pluto, researchers made progress on finding and eradicating dormant HIV in infected cells, designed protective gear for doctors caring for Ebola patients, scientists studied threats to ocean ecosystems from Hg in dolphins and an accelerating buildup of CO_2. The JHU research was supported by the return on investment made from past discoveries. In 2014 reported earnings of 16.5 million US$ by licensing patented technology and 17.9 million US$ in 2015. JHU in 2014 spun off 13 new companies and received 92 new patents.[47]

Most of the statistical data for the R&D expenditure of the USA academic institutions are derived from the National Science Foundation (NSF) Higher Education Research and Development, Fiscal Year 2015. The Federal share of university R&D remained around 60% and historically played a major role in R&D funding. The NSF funding was around US$ 8 billion (1960) and increased to more than $40 billion in the last years distributed to 645 universities and colleges, out of a total R&D expenditure of US$ 67 billion in 2013.[48]

6. R&D for Technological Innovation in the United Kingdom

The United Kingdom (UK, England, Scotland, Wales, N. Ireland) is the world's 5th-largest economy by nominal GDP, the world's first industrialised country and the world's foremost economic and military power during the 19th and early 20th centuries. The UK has 127 universities and higher education institutions. The UK service sector makes up around 73% of GDP with London the world’s largest financial "command centres" of the global economy (alongside New York, Tokyo, Frankfurt). London has the highest educated population in the world and the highest per capita income in the world. London is a leading global city, in the arts, commerce, education, entertainment, fashion, finance, healthcare, media, professional services, research and development, tourism, and transport. The UK attracts large investment funds for industrial innovations. Its pharmaceutical industry plays an important role in the UK economy with the third-highest share of global pharmaceutical R&D expenditures (after the United States and Japan). The UK space industry was worth £9.1billions in 2011. The aerospace industry of the UK is the 2nd- or 3rd-largest national aerospace industry in the world. The automotive industry is a significant part of manufacturing sector and employs around 800,000 people, with a turnover in 2015 of some £70 billion [Office of National Statistics, *UK 2015: The Official Yearbook of the United Kingdom of Great Britain and Northern Ireland*].

In 2013, UK expenditure for R&D was £28.9 billion (43.5 US$). In 2014, the gross domestic expenditure on R&D, in current prices, increased by 5% to £30.6 billions (yearly increase of 3%). The business sector accounted for £19.9 billion of expenditure in 2014 (65% of total expenditure), represented 1.67% of Gross Domestic Product (GDP) which is below the European Union (EU-28) provisional estimate of 2.03% of GDP. Despite the low percentage of GDP among European countries, the UK has one of the most innovative and advanced technological basis and produces high quality scientific publications, patents and technological discoveries. Statistical data on R&D are from the U.K. Office of National Statistics.[49]

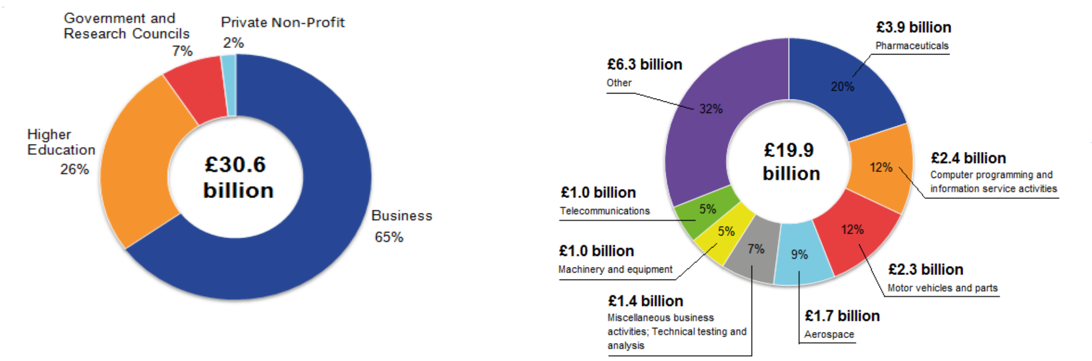


Figure 9. R&D annual expenditure 30.6 billion (2014). Expenditure subdivided by sector: UK Business 65%, Higher Education 26%, Government and Research Councils 7%, Private Non-profit 2%. **Business R&D £19.9 billion (2014).**. Pharmaceuticals (£3.9 billion), Computer programming and information service activities (£2.4 billion), Motor vehicles and parts (£2.3 billion), Aerospace (£1.7 billion), Miscellaneous business activities (£1.4 billion), Machinery and equipment (£1.0 billion), Telecommunications (£1.0 billion).[Office of National Statistics].

R&D in Higher Education institutions of the UK (2014) represented 26% of the total UK R&D expenditure at £7.9 billion, increasing by of 3% from £7.6 billion in 2013. The funding for this sector is mainly provided by the Higher Education Funding Councils, the seven UK research councils and the research funds from the European Union. Considering just Framework Programme funding of EU, UK universities were among the most successful in securing EU research funding, receiving 71% of total Framework Programme (FP7) funding awarded to the UK. A total of 13 UK universities are ranked in the top 25 European universities, rated in terms of the number of participations in Framework Programme 7. Oxford, Cambridge, Imperial College and University College of London occupied the top four spots and are among the 10 best world's universities. The EU has supported 3,539 UK based researchers to access 1,055 European research facilities between 2007 and 2013. Over the period 2007 – 2013, universities received €4.9bn out of a total of €6.9bn awarded to the UK through FP7 Framework Programme. In 2013-2014 the UK universities received £687 million of research income from EU.[50,51,52]

Pan-European research facilities in the UK. The UK hosts the headquarters of 6 pan-European research facilities, with facilities distributed across multiple participating countries.[53]

- High Power Laser Energy research Facility (HiPER) – Harwell, Oxfordshire (Central Laser Facility)
- ELIXIR (European Life-science Infrastructure for Biological Information) – Hinxton
- Integrated Structural Biology Infrastructure (INSTRUCT) – Oxford
- Infrastructure for Systems Biology-Europe (ISBE) – London (Imperial College)
- Square Kilometre Array (SKA) – Manchester (Jodrell Bank)
- European Social Survey (ESS ERIC) – London (City University).

The UK also hosts 10 facilities that are part of pan-European research facilities headquartered in other European countries and is a member of pan-European research facilities entirely based beyond its borders, such as the European Hard X-Ray Free Electron Laser (European XFEL) based in Germany.

The UK Science Parks Association lists over 100 locations in the UK (including Science, Research and Technology Parks, Technology Incubators and Innovation Centres) as its members. These provide the environments for 4,000 companies employing around 75,000 people. In 2012 the UK Government introduced Start Up Loans to provide finance and mentoring to young entrepreneurs. By 2013, over £45m (€56.25m) of loans had been made to 10,000 entrepreneurs. **International Comparative Performance of the UK Research Base** (BIS 2013), "while the UK represents 0.9% of global population, 3.2% of R&D expenditure, and 4.1% of researchers, it accounts for 9.5% of downloads, 11.6% of citations and

15.9% of the world's most highly-cited articles". The UK has now overtaken the US to rank 1st by field-weighted citation impact. In the UK, approximately 55,000 patent applications in the period 2000-2010, while around 64,000 patents. The UK is a highly productive research nation in terms of articles and citation outputs per researcher or per unit of R&D expenditure. In the UK there were 262,303 researchers in 2011 (expressed as full-time equivalents rather than as a simple headcount), representing 3.9% of the global total and increasing at just 0.9% per year over the period 2007-2011.[54,55]

7. Research & Development Expenditure in Japan

Japan is the world's 3rd-largest economy in terms of GDP with 4.807 billion (2014), 4.855 billions (2015) and 4.913 billion (2016, forecast). Japan as a highly industrialised country has some of the most successful motorcar and electronic industrial enterprises. Japan is home to some of the largest and most technologically advanced producers of motor vehicles, electronics, machine tools, steel and nonferrous metals, ships, chemical substances, textiles, and processed foods. As of 2014, Japan's public debt was estimated at more than 200 % of its annual GDP, the largest of any nation in the world. In 2014-2016 Japan's expenditure for research, development (R&D) and innovation was 3.4 % of GDP. The total gross expenditure was 166 US$ billion (forecast of 2016). [56]


Figure 10. Japan is a world leader in R&D with successes in the fields of electronics, semiconductors, automobiles, industrial robotics, optics and chemicals.

Japan is a world leader in fundamental scientific research, having produced 22 Nobel laureates in physics, chemistry and medicine. Some of Japan's more prominent technological contributions are in the fields of electronics, automobiles, machinery, earthquake engineering, industrial robotics, optics, chemicals, semiconductors and metals. Japan leads the world in robotics production. The Japan Aerospace Exploration Agency (JAXA) conducts space, planetary, and aviation research, and leads development of rockets and satellites. In 2014 Japan employed 844,000 scientific personnel for R&D and produced 265.959 patents on technological and natural science fields and Japanese scientists published 103.377 (2014) high quality scientific papers in the research journals. There are approximately 780 universities in Japan, of which about 80% are private. The nation's strongest global ranking is currently claimed by the University of Tokyo, which ranks 34th in the QS World University Rankings 2016/17. Close behind are (joint 37th) and Tokyo Institute of Technology (56th), with a further 36 Japanese universities ranked among the world's best.[57,58]

8. Research and Development Expenditure in China

Until 2015 China was the world's fastest-growing major economy, with growth rates averaging 10% over the ten years but lately dropped to 6.5%. China is the second largest economy after the USA and the largest manufacturing economy, as well as the largest exporter of goods in the world. In the last decades China is the world's fastest growing consumer market and second largest importer of goods and net importer of services products. China's population was in 2016 1.371.220 and its nominal GDP was 11.006 billion US$, but its GDP per capita was very low at 8.027 US$. Most of China's financial institutions are state owned and 98% of banking assets are state owned. China is the world's largest producer and consumer of agricultural products and there are some 300 million Chinese farmers. China's Industry and construction account for 47% of China's GDP. China ranked in the previous decade 3rd worldwide in industrial output after USA and the European Union, but after 2010 China contributed to 20% of world's manufacturing output and became the largest manufacturer in the world that year, after the US had held that position for about 110 years. In 2009 China manufactured 13.8 million motor vehicles thus becoming the number-one automaker in the world. Substantial investments in China were made in the manufacture of solar panels and wind generators by a number of companies, supported by liberal loans by banks and local governments. China has budgeted $50 billion to subsidize production of solar power over the two decades. As of 2011, China was the world's largest market for personal computers.[59,60,61]

Figure 11. China's manufacturing is increasing very fast mainly because costs are very low comparatively with other countries. Companies are investing in China for their manufacturing purposes as well as for the best suppliers in China.
[http://www.china2west.com/china-suppliers-china-quality-manufacturers/].

Research and development (R&D) spending in China reached one trillion yuan renminbi (RMB) (or US$ 164.1 billion) in 2012, about 1.98% of its GDP, viewed as an important indicator of a country's investment in research, engineering discoveries and innovation. According to the Global Competitiveness Report (by the World Economic Forum), China's innovation capabilities ranking rose to 26th in 2012 from 48th in 2006. Measured by purchasing power parity, China's Gross Expenditure on R&D (GERD) reached US$ 294 billion, behind the USA (GERD $454 billion) and the European Union's R&D (US$ 341 billion) but ahead of Japan's (US$152 billion). China's GERD (1.98%) more than tripled since 1995, surpassing the 28 member states of EU.[62,63,64]

According to the OECD report, China is forecast to overtake the USA in R&D spending by 2022. While China is ascending the global R&D ladder, it has work to do on improving the quality of its science, technology and innovation products. According to the report, China has the world's largest pool of human resources for science and technology but the university graduates and doctoral-qualified share of the population remains extremely low. The quality of Chinese science is still behind the world average, which is reflected by citation indicators (research papers, scientific reports, innovations, international patent, productivity) and the share of PhDs among researchers. Chinese universities awarded over 27,000 doctorates in science and engineering in 2011, more than the USA universities (24,792) [65]

In the last decades China increased substantially the numbers of research and technology institutions in universities and industrial enterprises. China attracted substantial amounts of investment in research, innovations and industrial production for the last decade. In 2015, China saw 453 organizations offering technology transfer services and 30 organizations dedicated to technology property transactions. China's gross technology trade amounts reached 983.5 billion yuan in 2015, up 14.7% from the year before. China moved up to 18th spot in 2015 in the rankings of countries' with innovative capacities. The rate of scientific and technological contributions may increase from 50.9% to 55%. In 2015, China's gross R&D expenditure amounts to 1.43 trillion yuan (registering a growth of 100 % (Wan Gang, China's Minister of Science and Technology). To date, China has more than 2,300 business start-up platforms, 2,500 technology business incubators, 11 national innovative demonstration zones and 146 national high-tech zones.[66]

9. Research & Development Expenditure in Germany

Germany is the 4th biggest economic world power and is considered as a leading powerhouse for industrial R&D and high valued innovative research and discoveries in German universities. Recently, Germany increased its R&D expenditure to 3% of GDP, the highest in EU (5th among the developed countries). Germany even beats the USA and is far ahead of France and UK, only South Korea and Japan's R&D intensity is higher than in Germany. In 2012, public and private spending on research projects was EUR 79.4 billion representing 2.98% of GDP. [67]

Figure 12. The new research campus in Renningen is to become the new hub of the Bosch Group's global research and advance engineering activities. The construction costs of the new campus was around 160 million Euros. Volkswagen (VW) is the single biggest industrial spender on R&D worldwide with US$17 billion on R&D in 2014. Second enterprise was Intel (USA) with US$13.6 billion for R&D.

In Germany, as in Japan and South Korea, more than 85% of R&D carried out in the private sector relates to manufacturing industries. The figure in the USA is less than 70%; in France it is just under 50% and in UK only 37%. R&D investment within German industry is also concentrated relatively highly within certain sectors.

Vehicle manufacturing, computing, electronics and mechanical engineering account for 55% of Germany's R&D, with vehicle manufacturing alone making up 31 %. Data on R&D are provided by the Scientific Commission of Experts for Research and Innovation (Expertenkommission Forschung und Innovation – EFI).[68]

Germany is home to approx. 400 higher education institutions which offer the entire range of academic disciplines: 110 universities (Universitäten), 230 universities of applied sciences (Fachhochschulen/Hochschulen für angewandte Wissenschaften), and 60 art- music colleges (Kunsthochschulen/Musikhochschulen). German universities have 380.000 academic staff (2014) and 2.8 million students of which 12,3% are foreign students. The gross domestic expenditure on R&D in universities was 14.9 billion euros (2014). The investment for R&D are 81% public, 14% from industry and 5% from international funds. The German Higher Education Institution system is characterised by a close link between learning, teaching and research. Also, Germany's universities attract every year 340,000 foreign students (1/6 of doctoral degrees in German universities are given to international students). German universities and research institutions have worldwide connections and a reputation for top-class research. In 2014, there were 85,000 international academics teaching and conducting research at German universities and non-university research establishments. This was found by the "Wissenschaft weltoffen 2016" report compiled by the German Academic Exchange Service(DAAD) in cooperation with the German Centre for Higher Education Research and Science Studies (DZHW). Over 40,000 academics work in German HEI and 18,000 researchers from other countries (mostly supported by EU funding). [69]

The Federal Government and the German states (Länder) have set up the Excellence Initiative that provides additional support for R&D activities in various disciplines at German universities. From 2006 to 2017 a total of 4.6 billion euros will be invested to promote top-level research and to further enhance the international competitiveness of German higher education and research. Within the framework of the Excellence Strategy these measures will be continued on a long-term basis. From 2018 onward, the Federal Government and the German states will yearly provide 533 million euros in funding for a limited number of excellence universities or university consortia and up to 50 excellence clusters. Universities and other HEI offer a broad spectrum of research activities, including basic research and applied research and development (R&D). It is estimated that 100,000 of Germany's 360,000 R&D researchers work at HEI and university hospitals. The largest share of R&D expenditure in Germany, roughly 4.2 billion euros, goes to the fields of mathematics and the natural sciences; they are closely followed by medicine and health research, which have access to roughly 3.4 billion euros a year.[69,70]

10. Research & Development Expenditure in Greece

The Greek economy during the period 1981–2007 went through a period of structural reforms and adjustments. The accession of Greece to the European Economic Community (EEC) in 1981 and the accession to the European Monetary Union (EMU) in 2001 were two major events. Positive growth rates were achieved in the 1990s and in the period 2000-2008 with average annual growth rate of GDP 2.4% in the 1990s and 4.1% during the period 2000–2007. Greece is a developed country with an economy based on the services (80%), the industrial sector is small (13 %) and the agricultural sector ~6-7% (for 2015). Two important economic sectors are Greek tourism and shipping. With more than 23 million tourists in 2015, Greece was the 7th most visited country in the EU and 16th in the world. The Greek Merchant Navy is the largest in the world. The economic crisis of 2009-2016 reduced substantially the GDP of Greece, from the highest point of 354 billion US$ (2008) to 235 billion US$ (2014) to 195 billion US$ (2015). Despite the significant increase in R&D expenditure in absolute terms, the R&D intensity has remained very low in comparison to the EU average (more than 2%). In 2015 the investment was 1.683 million (euros) or 0.96% of GDP.

Figure 13. Eurostat statistics for Greece in the period 2011-2014 with the effects of the economic crisis. The GDP of Greece from 207 billion euros (2011) decreased to 177 billion to 2014. The R&D expenditure increased slightly from 1.391 millions (2011) to 1.481 million (euros) in 2014. The % of GDP expenditure for R&D increased from 0.67% to 0.84% because of the fall of GDP (by ~30 billions).

Most of the funds (2015) were for the state budget and the EU. Government investment for R&D (2015) was 52% of the total amount, at 887 million euros. The expenditure was boosted by the funds of the EU under the ESPA programme (385 million euros for Greece in 2015). The ESPA or NSRF (ESPA = Εταιρικό Σύμφωνο για το Πλαίσιο Ανάπτυξης, or National Strategic Reference Framework, European Union) was a very promising financial fund programme for all European countries but it proved very important in Greece. For example, a total of 19 billion euros were approved for Greece by for the 7 years of 2014-2020 period. The funds will be distributed for manufacturing, tourism, energy and the agricultural and food industry. Other sectors in ESPA were research and technological development, aquaculture, specialty health services, creative development of cultural heritage, modern Greek creativity, pharmaceuticals industry, computer science, communications, waste management, trade, freight services [See more at: http://greece.greekreporter.com/2014/12/22/ nsrf-e19-billion-for-greece-in-the-2014-2020-program/#sthash.ikYx2mHM.dpuf].

[** ΕΣΠΑ (Εταιρικό Σύμφωνο για το Πλαίσιο Ανάπτυξης) 2014-2020, βασικό στρατηγικό σχέδιο για την ανάπτυξη της Ελλάδος με πόρους από τα Ευρωπαϊκά Διαρθρωτικά και Επενδυτικά Ταμεία (ΕΔΕΤ) της ΕΕ, συνδράμει στην επίτευξη των εθνικών στόχων έναντι της Στρατηγικής «Ευρώπη 2020» (προαγωγή της ανάπτυξης, αποτελεσματικότερες επενδύσεις στην εκπαίδευση, την έρευνα και την καινοτομία, οικονομία χαμηλών εκπομπών CO_2, κλπ.)].

The second most important contributor to R&D expenditure (2015) in Greece is the private sector with 534 million euros (or 32% of total) and 2,4 million euros from nonprofit organizations. Research found that the technological and research innovation network in Greece appeared to be built around a few highly connected central actors, which were the leading and more innovative Greek firms and the most reputed academic institutions and research centres (Demokritos, National Research Foundation, etc). The majority of Greek firms had very low or no systematic participation in R&D projects.[71,72]

In 2010, under the National Strategic Framework for Research & Innovation (2014-2020) Greece established the National Council for Research & Technology (NCR&T) (Εθνικό Συμβούλιο Έρευνας & Τεχνολογίας ΕΣΕΤ, 2010-2013) to advise the government on R&D and identify areas where critical mass exists to enable rapid progress and innovation, to promote and strengthen connections of the research establishment with the entrepreneurial Greek community. Members of NCR&T were well known professors from Greek and foreign universities: Prof. Stamatios Krimigis [(Johns Hopkins University, USA and Academy of Athens (Chair)], Prof. Chrousos G. [Medical School, University of Athens, (vice Chair)], Prof. Dafermos C [Brown University, USA (member)], Prof. Kevin Featherstone [London School of Economics, UK (member), Haliassos M (Goethe University, Frankfurt), Iliopoulos J (Ecole Normal Superiere, Paris), and others].

The Executive Summary of the NCR&T for the National Strategic Framework for Research & Innovation identified, "…..strengths and weaknesses of the R&D enterprise, while some areas where critical mass exists to enable rapid progress and innovation, promote and strengthen connections of the research establishment with the entrepreneurial community, and allocate investments in a fair and competitive manner. The NCR&T identified the development of a Strategic Plan as an important priority (2010) and a draft plan was completed in the fall of 2013. The principal goal of the strategic plan was the identification of areas of strength and excellence that can be further advanced and can become engines for progress and growth. The NCR&T found…":

1. Areas of traditional strength (examples: shipping, tourism, energy).
2. Areas of recent successes in terms of critical mass and on-going activities (examples: IT, pharmaceuticals, engineering, energy).
3. Areas of high added value and able to deliver major economic benefit and employment prospects (examples: energy, nutrition – food sciences).
4. Areas of major national interest (examples: food production, archaeology, culture, energy, defense, biomedicine).

The NCR&D set as a first priority the increased investment of R& from the current 0,6-0,8% of GDP to 1.5% of GDP by 2010. The NCR&D concludes that "…A sustainable long-term growth path for Greece will require investment in the creation of knowledge and the stimulus to innovation. Reviving GDP via a consumption-led boom will not meet the new European and international challenges that Greece faces nor represent the necessary break with past vulnerabilities. This National Strategic Framework for Research and Innovation (ΕΣΠΕΚ, Εθνικό Στρατηγικό Πλαίσιο Έρευνας και Καινοτομίας) must be seen as an integral part of a new 'smart' growth model – that is why NCR&T – (ΕΣΕΤ, Εθνικό Συμβούλιο Έρευνας και Τεχνολογίας) advances the need for a substantial increase in the share of GDP devoted to R&D in the 2014-2020 period, together with a range of targeted initiatives for research and innovation. This is not a matter of ideals, but rather of practical necessity: there is ample economic evidence of the role of investment in R&D as a key driver to sustainable, long-term growth. Over the last decade, Greece has been an outlier from this equation of R&D investment and overall growth: graph 2.1, for example, shows the levels of R&D investment amongst our EU partners and those of GDP growth in 2010.[73]

11. Industry-University Partnerships in R&D. Are they Important for Innovation and Technological Achievements?

Research and Development (R&D) is linked to new technological practices and innovation of new products, processes and methods. Innovation combines changes in technology, business models, organization, and in a competitive economy, no business and technological enterprises can survive long term without updating its products and services or the ways in which they are produced or delivered. Science-based competence plays an important role in industry's capacity to innovate, but there is no linear route from advanced research to innovation. The time from patented invention to a useful product took in most cases long time. For example, the float glass process was invented in 1902 and the commercial material produced in 1943, the fluorescent lighting was invented in 1901 and the product in 1938, the helicopter in 1904 and produced in 1936, the jet engine in 1904 and 1936, the tape recorder took 39 years to be produced (invented 1898), the radio took 18 years to produce, the television 13 years, and the synthetic detergent 42 years.[74]

Most of the advanced industrial firms invest 5-15% of their revenue every year for R&D expenditure. Also, it is well known that research-based competence and cooperation with academic research can contribute in many innovation processes by adding new competence, identifying new areas of knowledge that present future technological opportunities, or by identifying and solving crucial technological processes and fundamental scientific problems.[75]

The world's biggest industrial spenders on R&D in 2014 were **Volk**swagen (VW, Germany) with US$ 17 billion expenditure on R&D (in 2014), second was **Intel** (Santa Clara, California, U.S.) with $13.6 billion, third was **Samsung** (South Korea 2013): 13.4 US$ billion (6.4% of revenue), fourth was pharmaceuticals company **Roche** (Switzerland): $11.9 billion, fifth was **Microsoft** (U.S.): $11.9 billion, sixth was the IT company **Google** (U.S.): $10.9 billion, seventh the consumers company **Johnson & Johnson** (USA, The world's sixth-largest consumer health company): $10.3 billion, and then pharmaceuticals company **Novartis** (Switzerland): $10 billion, **Toyota** (automobiles, Japan) 9.1 $ billion (3.5% of revenue), pharmaceuticals and chemicals company **Merck** (New Jersey, USA) 7.5 $ billion (17% of revenue, 2013).[76]

University–industry links and their impact on innovation processes have been a longstanding object of analysis in various scholarly communities in management studies, the economics of innovation, industrial organization, the sociology of science and science studies, and science and technology policy. Factors such as changing legislative environments, the growing number of government initiatives to promote translational research and public–private research partnerships as well as increasing policy pressure for universities to help improve national economic competitiveness) have contributed to a growing involvement of universities with industry. This is indicated by various trends: an increasing patenting propensity by universities, growing university revenues from licensing increasing numbers of university researchers engaging in academic entrepreneurship a growing share of industry funding in university income and the diffusion of technology transfer offices, industry collaboration support offices and science parks.[77,78]

Factors such as changing legislative environments, the growing number of government initiatives to promote 'translational research' and public–private research partnerships as well as increasing policy pressure for universities to help improve national economic competitiveness have contributed to a growing involvement of universities with industry. This is indicated by various trends: an increasing patenting propensity by universities, growing university revenues from patent licensing, increasing numbers of university researchers, academic entrepreneurship, a growing share of industry funding in university income and the diffusion of technology transfer offices, industry collaboration support offices and science parks.[79,80,81,82]

Research papers evaluated the importance of innovation collaboration between university and industry. The data showed that there were differences between manufacturing and service firms and between small firms and larger firms. On balance, robust evidence was found that university collaboration positively influences innovation sales as well as the propensity to apply for patent for manufacturing firms with more than 100 employees.[83] An empirical study analyzes 2010 data for Spanish public universities and their R&D activities. Results indicated that successful R&D contracts depend on university and Technology Transfer Offices characteristics, and the university's location. The study also presented a set of managerial implications for improving the establishment of university–industry partnerships to become more affective and promote technological innovations.[84]

In September 2015 Thomson Reuters published its *Ranking of Innovative Universities* (RIU). Covering 100 large research-intensive universities worldwide, which have very innovative technological laboratories and partnerships with industry. First on the top was Stanford University (U.S), MIT (*Massachusetts* Institute of *Technology*) was second and third was Harvard University (Cambridge, MA, US). Harvard University is the oldest EHI in the U.S., and has produced 47 Nobel laureates over the course of its 380-year history. Studies projected these partnerships and the outcome by various types of metrics available. One metric in particular was university–industry co-authored publications (derived from the bibliometric analysis of 750 research universities). The analysis of all data showed that universities-industry R&D increased university competitive ranking in innovation and technological achievements.[85,86]

Although Stanford is 9th in the list of U.S HEI for R&D expenditure, is leading the Reuters Top 100 World's Most Innovative Universities. The Stanford University is located in the heart of California's Silicon Valley and has earned a reputation as a hotbed for innovation in computer hardware and software: The university's faculty members (professors, researchers, engineers) and alumni (older graduates who work in innovative technological enterprises) have founded some of the biggest technological companies in the world, including Hewlett-Packard, Yahoo and Google. A 2012 study by the university estimated that all the companies formed by Stanford entrepreneurs generated total global revenue of $2.7 trillion annually. [86]

Outside the U.S. half of Reuters Top 100 Innovative Universities are located in Canada, Europe or Asia (China, South Korea and Japan). Japan is home to 9 of the most innovative universities - more than any other country except the U.S. Also, South Korea performs well on the list: the Korea Advanced Institute of Science & Technology (KAIST), is the only non-U.S. university to place in the top No. 10. According to the list, the most innovative university in Europe was Imperial College (one of the University of London institutions, ranked No.11). The No. 16 was Katholieke Universiteit Leuven (Catholic University at Louvain, Belgium) and at No. 25 the University of Cambridge. Elsewhere in Europe, Switzerland with 3 universities on the list, has more innovative universities (on the top 100) per capita than any other country in the world.[85.86]

Some of the universities in the Reuters 100 top innovative list are (for 2015) :

1.Stanford, 2. MIT, 3. Harvard, 4. University of Washington, 5. Univ of Michigan, 6. Northwestern Univ., 7. Univ. of Texas System, 8. Univ. of Wisconsin System, 9. Univ. of Pennsylvania, 10. Korea Advanced Institute of Science and Technology (KAIST), 11. Imperial College, Univ. of London,,16. KU Leuven (Belgium), 18. Osaka University (Japan), 22. Kyoto University (Japan), 24. Univ. of Tokyo (Japan), 25. University of Cambridge, 27. École Polytechnique Fédérale de Lausanne.. 31. Seoul National University, .37. Swiss Federal Institute of Technology Zurich, 40. University of Oxford, 75. Tel Aviv Univ., 95. Univ. of Manchester…etc].[85,86]

The full list of the 100 most innovative institutions broken down by country includes 46 universities from the United States;, 9 from Japan; 8 each from France and South Korea; 7 from Germany; 5 from the United Kingdom; 3 each from

Switzerland, Belgium, and Israel; 2 each from Denmark, China, and Canada; and 1 from both Singapore and the Netherlands. All of these universities produce original research, create useful technology, and stimulate the global economy.[85]

The Reuters Top 100 most innovative universities for 2016 published in September 2016 and has slightly different ranking for some of the universities, but also big changes for KAIST, KU Leuven and Pohang University in S. Korea.[86]

The 2016 list: 1.Stanford, 2. MIT, 3. Harvard Univ., 4. Univ. Texas System, 5. Univ. Washington System, 6. KAIST (S. Korea), 7. Univ. Michigan System, 8. Univ. of Pennsylvania, 9. KU Leuven, 10. Northwestern Unv., 11. Pohang University of Science and Technology (POSTECH, S. Korea). 12. Imperial College London. [86]

The big change from the previous year 2015 (elevated to No. 11) is the Pohang University of Science & Technology (POSTECH) in South Korea. It is a private research-oriented university with unique ties to industry. Its 400-acre university campus is located only a few minutes away from the big industrial enterprise of POSCO headquarters (a multinational steel-making company). POSTECH's revenue from research grants and contracts was more than US$149 million in fiscal 2015. The university's 72 research units include the Institute for CO_2 reduction and Sequestration, the Intelligent Robotics Laboratory and the Machine Learning Center. The Pohang Accelerator Laboratory has the only synchrotron radiation accelerator in Korea.

The well known weekly *Times Higher Education* (Supplement) publishes every year, in collaboration with Elsevier, a list of the world of the best and most innovative universities. The list of university innovations and inventions are calculated taking into account four indicators: the ratio of papers co-authored with industry, the proportion of papers cited by patents, the quantity of research income from industry and the proportion of research income from industry.[87]

There are great differences among universities in developed countries for industry-university partnerships and funding for R&D from state and private enterprises. In China, for example, universities receive only 8% of national research funding directly, but they also work closely with government-controlled enterprises that receive the majority of China’s R&D funds. In China, academics are given a bonus salary for patenting, even if it is not commercialized. Researchers in Europe get a “minuscule proportion” of royalties in comparison. An example, China’s Southwest Petroleum University has the highest percentage of papers co-authored with industry while the US’ Scripps Research Institute, which conducts biomedical research, produces the highest proportion of papers that have been cited by patents. Ludwig Maximilian University of Munich, one of Germany’s oldest universities, claims the largest quantity of research income from industry, and the Siberian State University of Geosystems and Technologies has the highest proportion of income from industry sources. The Netherlands' Eindhoven University of Technology, which produces the seventh-highest proportion of papers co-authored by industry, according to the innovation indicators, also refuses to conduct research with industry that cannot be published. But Eindhoven's collaboration with business goes further than that of many institutions. Of its 300 professors, half work full time and are employed by the university. The other half are part time and about 80% of staff in this group are employed by industry, splitting their time between working at the university and working in business. The university agrees to fund half the cost of long-term research programmes with industry, as long as the academics involved can secure the rest of the funding from business. One-third of its €300 million annual budget comes from industry or European funding, with the rest from government.[88]

The innovation among Europe's universities is, to some extent, reflected in the broader national pictures. The World Economic Forum's Global Competitiveness *Report 2015-2016* found Switzerland, Finland and Israel are the 3 most innovative countries in the world, U.S., Japan and Germany ranked No. 4, 5 and 6th. Sweden, Netherlands, Singapore and Denmark (7, 8, 9 and 10) Taiwan is No. 11 and United Kingdom No. 12. [89]

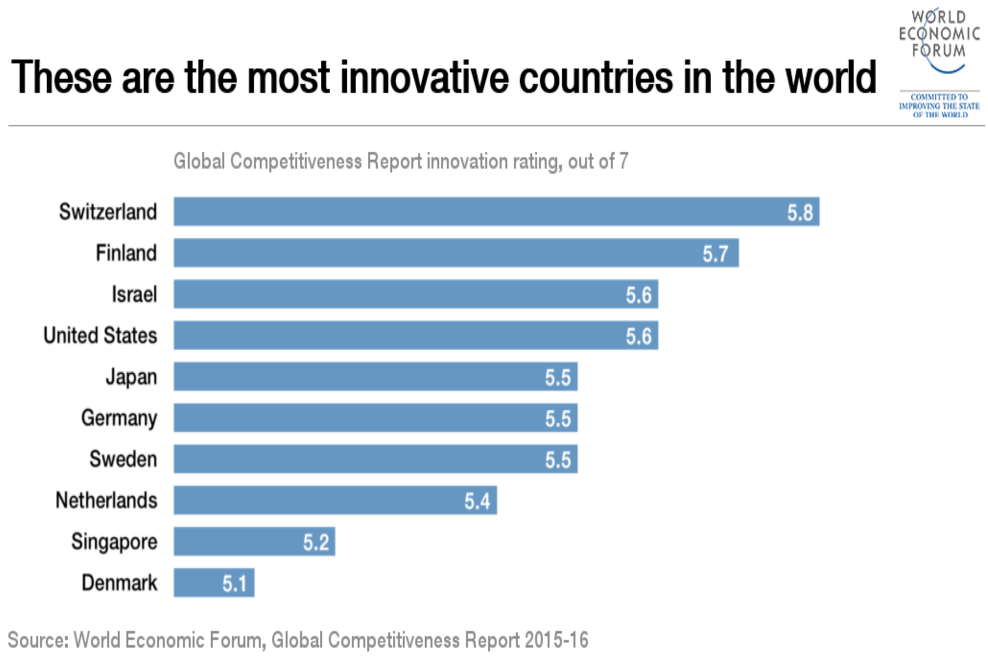


Figure 14. The World Economic Forum, using data for R&D expenditure of GDP, the university-industry relationships for R&D and competitive ranking in technological discoveries and innovations for 2015-2016.

Another Global innovation index among industrial countries takes into account investments in R&D, quality of universities, collaboration among universities and industry, publications of research papers in high impact journals, patent filings and successful applications for economic growth. The innovation Inputs are: Institutions (political, regulatory, business environment), Human capital and research (education, tertiary education, R&D). Infrastructure (ICTs, ecological sustainability), Market sophistication (credit, investment, trade), Business sophistication (knowledge workers, innovation linkages, knowledge absorption). Innovation Outputs taken into account are: Knowledge and technology outputs (creation, impact and diffusion of knowledge), Creative outputs (intangible assets, creative goods and services, online creativity). With these criteria, the collaboration of Cornel University, World Intellectual Property (WIPO) and INSEAD Knowledge, The Business School of the World (Institute Europeen d'Administration des Affaires) has produced an authoritative and balanced list of *The World's Most innovative Countries* for 2016.[90]

The List for 2016 was: 1. Switzerland (also, number 1 in 2015), 2. Sweden, 3. United Kingdom, 4. United States of America, 5. Finland, 6. Singapore, 7. Ireland. 8. Denmark, 9. Netherlands, 10. Germany, 11. Republic of Korea, 12. Luxembourg, 13. Iceland, 14. Hong Kong (China), 15. Canada, 16. Japan, 17. New Zealand, 18. France, 19. Australia, 20. Austria, 21. Israel, 22. Norway, 23. Belgium, 24. Estonia, 25. China. [http://www.wipo.int/pressroom/en/articles/2016/article_0008.html].

Studies showed that innovation in the three sectors of the economy (agriculture, industry and services) is critical to raising long-term economic growth. Worldwide, in the current economic climate it is imperative to discover new energy sources, environmentally friendly processes for sustainable development, and uncovering new sources of growth and leveraging the opportunities raised by global innovation. Sustainable development requires radical and systemic innovations because the world is facing a significant number of long term challenges including climate change, population ageing, desertification, water scarcity, pollution, and critical raw materials scarcities. At the same time, the international economic context has moved to a new, multi-polar era in which the rules of the competitive game are being reset. The policies that have ruled international competitiveness are rapidly changing in the last decade. The financial crisis that started in 2008 has made it abundantly clear how short term-profitability mindsets and related strategies, policies and actions of individuals and individual firms can cause global economic, ecological and ethical crises.[91]

Conclusions

Empirical evidence has suggested that Research and Development (R&D) expenditure and investment in the high technological sectors is positively related to economic growth of a country. High-technological industrial R&D spending has a strong positive effect on Gross Domestic Product (GDP). Quality of university research, investment in R&D and entrepreneurial initiatives can play a very important role. University-industry relationships can promote collaborative actions, extensive research discoveries and development of new and innovative products. In the last decades many governments have vastly increased their economic and policy commitments to innovation with significant impacts on levels of R&D expenditures of their countries. Since the mid-90s, along with the information technology revolution, high-technology industry is playing a key role in promoting economic development. Innovation is regarded as a major force in developing the positive relationship between high-technology goods and economic growth. Sustainable economic growth in the last decade has been expanded from the U.S.A, Canada, Western Europe, and Japan to the newly industrialized economies of East Asia (China, India, South Korea, Taiwan, Indonesia) and Latin America (Brazil, Mexico, Argentina) countries, and has contributed greatly to their national economic growth.

Recently, (EurActiv 14.11.2016) Carlos Moedas, Commissioner for Research, Science and Innovation in EU countries, praised the increased spending in R&D in the EU. He said "…The EU has only 7% of the world's population, but we produce 1/3 of the world's knowledge. However, while Europe has been very good at turning euros into knowledge, it has not been so successful at turning knowledge into euros. So we need to get better at translating excellent research into new products, processes and services that boost growth and jobs. The EU still has a considerable performance lead over many other countries, as attested by the European Innovation Scoreboard 2016 and is catching up with Japan and the USA. The 4th industrial revolution is driven by technology. But R&D is just one side of the coin. The right framework conditions must accompany any financing and investment in R&D. This means resolving new regulatory challenges and implementing legislation related to issues such as confidentiality of data, access to systems and protection against cyberattacks. The remaining regulation must remain light and easy, to make investment attractive for venture capital.[92]

References

1. Romer PM. Endogenous technical change. *J Polit Econ* 98: 71–102, 1990.
2. Verspagen B. *Economic Growth and Technological Change*. An Evolutionary Interpretation. OECD publications, Paris, 2001.
3. Jones CI. Growth and ideas, In: Aghion P, Durlauf SN.(Eds.), *Handbook of Economic Growth*, North-Holland publisher, Amsterdam, 2005.
4. Mokyr J. Long-term economic growth and the history of technology, In: Aghion, P, Durlauf SN (Eds.), *Handbook of Economic Growth*, North-Holland, Amsterdam, 2005.
5. Guellec D, Van Pottelsberghe de la Potterie, B. R&D and productivity growth – a panel data analysis of 16 OECD countries. *OECD Economic Studies*, Paris, **33**:103–126, 2002.
6. Guellec D, Van Pottelsberghe de la Potterie B. The impact of public R&D expenditure on business R&D. *Economics of Innovation and New Technologies* **12:** 225–244, 2003.
7. UNESCO Office of Public Information. Science for the twenty-first century. The 20th century: 100 years of scientific creativity. [http://www.unesco.org/bpi/science/content/press/anglo/6.htm].
8. Meyerson B. Top 10 emerging technologies of 2015. *Scientific American* 4/3/2015, [https://www.scientificamerican.com/article/top-10-emerging-technologies-of-20151/].
9. Park WG. International R& D spillovers and OECD Economic growth. *Economic Inquiry* 33(4):571-591, 1995.
10. Coe DT, Helpman E. International R&D spillovers. *European Econ Review*, 39, 859–887, 1995.
11. Coe DT, Helpman E, Hoffmaister AW. International R&D spillovers and institutions. *European Econ Review* 53(7):723-741, 2009.
12. Laursen K, Salter A. Searching high and low : what types of firms use universities as a source of innovation? *Res Policy* 33(8):1201-1215, 2004.
13. Mansfield E, Lee J-Y. The modern university: contributor to industrial innovation and recipient of industrial R&D support. Res Policy 25(7):1047-1058, 1996.
14. Maietta OW. Determinants of university–firm R&D collaboration and its impact on innovation: A perspective from a low-tech industry. *Res Policy* 44(7):1341-1359, 2015.
15. Etzkowitz H. Innovation in Innovation: The Triple Helix of University-Industry-Government Relations. *Social Sci Informat Sci Sociales* 42(3):293-337, 2003.
16. Etzkowitz H. *The Triple Helix. University-Industry-Government Innovation in Action* . Routledge publs, New York, 2008.
17. Viale R, Etzkowitz H (Eds). *The Capitalization of Knowledge. A Triple Helix of University-Industry-Government*. EE Edward Elgar, Cheltenham, Glos, UK, 2010.
18. Etzkowitz H, Webster A, Gebhart C,Terra BRC. The future of the university and the university of the future: Evolution of ivory tower to entrepreneurial paradigm. *Research Policy* 29 (2): 313–330, 2000.
19. Urbano D, Guerrero M. Entrepreneurial universities. Socioeconomic impacts of academic entrepreneurship in a European region. *Econom Develop Quanrterly* 27(1):40-55, 2013.
20. Allen S., Link A, Rosenbaum D. Entrepreneurship and human capital: Evidence of patenting activity from the academic sector. *Entrepreneurship Theory Practice* 31, 937-951, 2007.
21. Organization of Economic Cooperation and Development (OECD, 2016), Gross domestic spending on R&D (indicator). DOI: 10.1787/d8b068b4-en (Accessed

on 30 September 2016) [https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm]
22. EUROSTAT. The Eurostat in the EU devotes a special section where Statistics are Explained for R&D Expenditure .[http://ec.europa.eu/eurostat/statistics-explained/ index.php/R_%26_D_expenditure.] (accessed October 2016).
23. EC. European Commission. Horizon 2020. The EU Framework programmme for Research and Innovation. 2016. [http://ec.europa.eu/programmes/ horizon2020/en/] (accessed October 2016).
24. OECD, 2016, % of Gross domestic spending (GDS) on Research and Development (R&D) for selected developed countries doi: 10.1787/d8b068b4-en (accessed October 2016).
25. Research and development (R&D) - Gross domestic spending on R&D. OECD Data"*. data.oecd.org*. (retrieved 2016) [http://www.stats.gov.cn/tjsj/sjjd/201605/t20160531_1362661.html].
26. R&D Magazine. R&D 2016 Global R&D Funding Forecast. A Supplement to R&D Magazine, Winder 2016. Industrial Research Institute, www.iriweb.org, www.rdmag.com, Rockaway, NJ, USA. [https://www.iriweb.org/sites/ default/files/2016GlobalR%26DFundingForecast_2.pdf
27. Kigotho W. China heads for top of world in R&D spending – OECD. University World News. 14.12.2014, No. 343 [http://www.universityworldnews.com/ article.php?story=20141114112226407
28. Guo D, Guo Y, Jiang K. Government-subsidized R&D and firm innovation: Evidence from China. *Res Policy* 45(6):1129-1144, 2016.
29. AIP American Institute of Physics. Report: US Global Lead in R&D at risk as China rises. The AIP Bulletin of Science Policy News 1.2.2016 [https://www.aip.org/fyi/2016/report-us-global-lead-rd-risk-china-rises].
30. Falk M. What drives business research and development (R&D) intensity across Organisation for Economic Co-operation and Development (OECD) countries? Applied Economic 38(5):533-547, 2007.
31. Adams JD, Chiang EP, Starkey K. Industry-University cooperative research centers. *J Technol Transfer* 26(1):73-86, 2001.
32. Adams JD, Chiang EP. *Starkey K.* Industry–university cooperative research centers. *J Technol Transfer 26(1–2):73–86, 2001.*
33. Furman JL, MacGarvie MJ. Universities and technology transfer in Japan: Recent reforms in historical perspective. *J Technol Transfer*, 25:213–22, 2007.
34. Grady R, Pratt J. Academic science and the birth of industrial research laboratories in the U.S. pharmaceutical industry. *J Econom Behavi Organizat*, 63:756–7, 2000.
35. Hall B. The UK technology transfer system: Calls for stronger links between higher education and industry. *J Technol Transfer*, 25(2):205–211, 2004.
36. Lee Y. The sustainability of university-industry research collaboration: an empirical assessment. *J Technol Transfer, 25*(2), 111–131.2000
37. Perkman M, Walsch K**.** University–industry relationships and open innovation: Towards a research agenda. *Int J Manage Reviews* 9(4):259-280, 2007.
38. Morandi V. The management of industry–university joint research projects: how do partners coordinate and control R&D activities? *J Technol Transfer* 38(2):69-92, 2013.
39. Cunningham JA, Link AN. Fostering university-industry R&D collaborations in European Union countries. *Int Entrepren Manage J* 11(4):849-860, 2015.
40. Science-to-Business Marketing Research Centre (S2BMRC) *The State of European University-Business Cooperation Final Report - Study on the Cooperation between Higher Education Institutions and Public and Private Organisations in Europe*, Münster, Germany, 2011. Each country study is titled “The State of University-Business Cooperation in [the country], and each report is available at http://www.ub-cooperation.eu/index/, 2011.

41. Davey T., Baaken T, Galán-Muros V, Meerman A. Study on the cooperation between higher education institutions and public and private organisations in Europe, European Commission, DG Education and Culture, Brussels, Belgium, 2011.
42. Hall BH. University-industry research partnerships in the United States. In: Contzen J, Gibson D, Heitor MV (Eds.). *Rethinking Science Systems and innovation Policies*. West Lafayette: Purdue University Press, pp. 1-31, 2004.
43. Hülsbeck M, Lehmann EE, Starnecker, A. Performance of technology transfer offices in Germany. *J Technol Transfer, 38*, 199–215, 2013.
44. Link AN, Wessner CW. Universities as research partners: Entrepreneurial explorations and exploitations. In: Audretsch D (Ed.). *Handbook of Research on Innovation and Entrepreneurship*. Edward Elgar Publishing, London, pp. 290-299, 2011.
45. Eid A. Higher education R&D and productivity growth: an empirical study on high-income OECD countries. *Applied Economics* (on line) 18.5.2010.
46. BestColleges.com**:** Highest Research & Development Funding [http://www.bestcolleges.com/features/colleges-with-highest-research-and-development-expenditures/]. (accessed October 2016).
47. HUB Johns Hopkins. Johns Hopkins leads U.S. in research spending for 36th year in a row. 2,24 US$ billions spent on medical, science, engineering research in financial year 2014. [https://hub.jhu.edu/2015/12/09/research-funding-leader-nsf-survey/] (accessed October 2016).47
48. American Association for the Advancement of Science, AAAS, R&D in Universities and Colleges. https://www.aaas.org/page/rd-colleges-and-universities] (accessed October, 2016). *Posted in HUB. University News, Health, Science +Technology* [http://hub.jhu.edu/2015/02/06/research-spending-rankings-nsf/] (accessed October 2016).
49. U.K. Office of National Statistics. UK Gross domestic expenditure on R& D in 2014. Estimates of R&D in Business Enterprise, Higher Education, Government, which includes Research Councils and private Non-profit [http://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/ukgrossdomesticexpenditureonresearchanddevelopment/2014].
50. Royal Society. UK Research and the European Union. The Role of the EU in Funding UK Research. Royal Society, London, 2016 [https://royalsociety.org/~/media/ policy/projects/eu-uk-funding/uk-membership-of-eu.pdf].
51. League of European Research Universities 2011, The European Research Area: Priorities for Research Universities: LERU Response to the European Commission Consultation "The European Research Area Framework, Untapped Areas of Potential" [http://www.leru.org/files/publications/ LERU_AP9_ERA. (accessed 2016)
52. European Parliamentary Research Service Briefing 2015, Overview of EU funds for research and innovation [http://www.europarl.europa.eu/RegData/etudes/ BRIE/ 2015/568327/EPRS_BRI(2015)568327_EN.] pdf ,(accessed 2016)
53. The Royal Society. How does the EU fund research facilities and major equipment? 2016 [https://royalsociety.org/topics-policy/projects/uk-research-and-european-union/role-of-EU-in-funding-UK-research/how-does-eu-fund-research-facilities-major-equipment/] (accessed, Sept, 2016).
54. International Comparative Performance of the UK Research Base – 2013 A report prepared by Elsevier for the UK's Department of Business, Innovation and Skills (BIS). Sci Val , Elsevier, 2013.
55. Elsevier. UK Continues to Punch Above its Weight in the Research Arena. *Most productive relative to R&D spend compared to the world's major research nations*, London, December 6, 2013 [https://www.elsevier.com/about/press-

releases/science-and-technology/uk-continues-to-punch-above-its-weight-in-the-research-arena]
56. R&D Magazine, R&D Investments Continue to Grow, As Do Their Past Trends winder 2016 issue [https://www.iriweb.org/sites/default/files/2016GlobalR%26DFundingForecast_2.pdf].
57. Japan, National Institute of Science and Technology Policy (NISTEP) » Research » R&D and Innovation [http://www.nistep.go.jp/en/?page_id=50]
58. Digest of Japanese Science and Technology Indicators 2016, Aug. 2016 Research Unit for Science and Technology Analysis and Indicators National Institute of Science and Technology Policy, MEX [http://www.nistep.go.jp/wp/wp-content/uploads/NISTEP-RM251-SummaryE.pdf].
59. National Bureau of Statistics (NBS) the annual data of China's GDP: published on China NBS: National data - annual - national accounts - Cross Domestic Product; Figures for the current year 2015 are based on the *Statistical Communiqué of the People's Republic of China on the 2015 National Economic and Social Development*.
60. Trading Economics. China Manufacturing Production 2013-2016. [http://www.tradingeconomics.com/china/manufacturing-production].
61. China in Brief 2007. Machinery Manufacturing and Automobile Industries [[http://www.china.org.cn/english/features/China2007/238565.htmustries]
62. ChinaDaily.com,cn. China’s spending 1.98% of GDP on R&D (22.10.2013) [http://www.chinadaily.com.cn/business/chinadata/2013-10/22/content_17050707.htm
63. Ni X. China's research & development spend. *Nature* 520:S8-S9, (30.4.) 2015. DOI:10.1038/520S8a
64. Sun Y, Cao C. Demystifying central government R&D spending in China. *Science* 345:1006-1008, 2014.
65. Kigoto W. China heads for top of world in R&D spending–OECD. *University World News*, 14.11.2014 [http://www.universityworldnews.com/ article.php?story=20141114112226407]..
66. China's 2015 ratio of R&D expenditure to GDP expected to be 2.1%, missing 2.2% target for 12th Five-Year plan. People's Daily Online, 17:15, January 12, 2016 [http://en.people.cn/n3/2016/0112/c98649-9002610.html].
67. GTAI. Germany Trade and Investment. The R&D Landscape. 2016 [[https://www.gtai.de/GTAI/Navigation/EN/Invest/Business-location-germany/RD-framework/rd-landscape.html]
68. Zimmermann V. KFW RESEARCH (KfW Banking Group, DIW Berlin) Focus on Economics. No. 105, 25th August 2015. An international comparison of R&D:*1 Germany benefits from industrial research strength.
69. Research in Germany. Land of Ideas. Universities. 2016. [http://www.research-in-germany.org/en/research-landscape/research-organisations/universities.html] (accessed Nov. 2016).
70. German Rector’s Conference, 2016 HRK The Voice of the Universities, Bonn, Germany. [www.hrk.de] . Research achievements in German universities [www.gate-germany.de]. (accessed Nov. 2016).
71. Tomadaki D. The formation of R&D networks: The case of Greece. Paper to be presented at the DRUID PhD Winter Conference 2005. [http://www.druid.dk/uploads/tx_picturedb/dw2005-1631.pdf].
72. The National Documentation Centre {Εθνικό Κέντρο Τεκμηρίωσης, EKT} provides the official statistics on Research, Development and Innovation in Greece, a task started in 2012. EKT performs statistical surveys and compiles the RDI statistics of the Commission Implementing Regulation (EU) 995/2012 for Greece (expenditure, personnel, community innovation surveys).(www.ekt.gr). Publication: "Innovation, Research and Technology" magazine , http://www.ekt.gr/en/magazine).

73. General Secretariat for Research and Technology.National Strategic Framework for Research and Innovation, 2014-2020, pp.1-74 2014. [http://www.gsrt.gr/Financing/Files/ProPeFiles81/ESPEK%202014-2020%20by%20ESET%282010-2013%29.FIN.v.3.pdf].
74. Clark J, Freeman C, Soete L. Long waves, inventions and innovations. *Futures* 13, 308–322, 1981.
75. Lennard Elc-Vinnova. Innovation and New Technology. What is the Role of Research? Implications for Public Policy, April, 2014. VINNOVA. Swedish Government Agency for Innovation Systems. [http://www.vinnova.se/upload/EpiStorePDF/va_14_05.pdf].
76. Fortune magazine, The Top-10 biggest R&D spenders worldwide, 17.11. 2014. [fortune.com/2014/11/17/top-10-research-development].
77. Perkmann M, Walsh K. University-industry relationships and open innovation: towards a research agenda. *Int J Manage Reviews* 9(4):259-280, 2007.
78. Hall BH. University-industry research partnership in the United States. Report of the European University Institute, Dpt of Economics, San Domenico (FI), Italy, 2004 [http://cadmus.eui.eu/bitstream/id/1735/EC/].
79. Mowery D, Nelson R, Sampat B, Ziedonis A. Ivory Tower and Industrial Innovation. Stanford Business School Press, Stanford, USA, 2005.
80. Shane S. Encouraging university entrepreneurship? The effect of the Bayh-Dole Act on university patenting in the United States. *J Busin Venturing* 19(1):127-151, 2004.
81. Santoro MD, Gopalakrishman S. The institutionalization of knowledge transfer activities within industry–university collaborative ventures. *J Enginner Technol Manage* 17(3-4):299-319, 2000.
82. Morandi V. The management of industry–university joint research projects: how do partners coordinate and control R&D activities? *J Technol Transfer* 38(2):69-92, 2013.
83. Lööf H, Broström A. Does knowledge diffusion between university and industry increase innovativeness? *J Technol Transfer 33*(1): 73–90, 2008.
84. Berbegal-Mirabent J, Garcia JLS, Ribeiro-Sorian DE. University–industry partnerships for the provison of R&D services. *J Busin Res* 68(7):1407-1413, 2015.
85. Ewalt D. REUTERS. The World's Most Innovative Universities (the Top 100), 2015.15.9.2015 (http://www.reuters.com/article/idUSL1N11K16Q20150915).
86. Ewalt D. Reuters Top 100: The World's most innovative universities-2016. 28.9. 2016. [http://www.reuters.com/article/amers-reuters-ranking-innovative-univers-idUSL2N1C406D].
87. Tijssen RJW, Yergos-Yergos A, Winnink JJ. University–industry R&D linkage metrics: validity and applicability in world university rankings. *Scientometrics* 109(2):677-696, 2016.
88. Bothwell E. Which universities are the most innovative? August 20, 2015. Times Higher Educational Supplement [https://www.timeshighereducation.com/features/which-universities-are-the-most-innovative].
89. World Economic Report (Prof. Schwab K, Prof. Sala-i-Martin X). Insight Report. *The Global Competitive Report 2015-2016*. WER publications, Geneva, 2015. [http://www3.weforum.org/docs/gcr/2015-2016/Global_Competitiveness_Report_2015-2016.pdf].
90. INSEAD, Cornel University and WIPO. *The World's Most innovative Countries* in 2016. [http://knowledge.insead.edu/entrepreneurship/the-worlds-most-innovative-countries-2016-4864#0G680GPIkAPqXCPc.99]. The Global Innovation Index 2016: Winning with Global Innovation is the result of a collaboration between Cornell University, INSEAD, and the World Intellectual Property Organization (WIPO) as co-publishers, and their partners.

91. Boons F, Montaivo C, Quist J, Wagner M. Sustainable innovation, business models and economic performance: an overview. *J Cleaner Prod* 45:1-8, 2013.
92. EurActive 14/11/2016, Moedas: 'Countries that increased spending in R+D better weathered the crisis' [http://www.euractiv.com/section/innovation-industry/interview/ moedas-countries-that-increased-spending-in-rd-better-weathered-the-crisis/?nl_ref=24918721]