Measurement of innovation, productivity and growth

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Economics of innovation

Measurement of innovation, productivity and growth

Outline:

- How can innovation be measured?
- Illustrations of innovation statistics
- Productivity at the firm, industry and economy level
- Comparing productivity and growth across countries

Introduction

- The basic motivation for this lesson is to convey that innovation and its implications can be measured and analysed
  - There are many problems in this process, but this is true across all of economic policy
  - Without measurement & analysis, understanding and policy will be based on rhetoric, anecdote and lobbying

- Since ‘innovation’ is defined as ‘new ideas that add value’, this automatically means that innovation is driving force behind growth
  - Clearly some authors think of technology, or human capital, as driving growth. We argue that ‘innovation’ is a better generic term.

How can innovation be measured?

- Surveys
  - ask to the firms about their activities
- Input measures
  - R&D is main measure
- Output measures
  - Patents and other Intellectual Property
  - Ultimately, productivity and growth are the outputs
- Note that Innovation Indexes tend to mix up inputs and outputs in very ad hoc way

Advantages and disadvantages of patents as indicators

The positive benefits of patents as indicators of innovation are:

- patents indicate an invention that is often a precursor to an innovation;
- they represent inventions with an expected value above the cost of patenting;
- the invention has been subjected to a test for novelty and nonobviousness;
- patents are classified by technical fields providing information about changes in the directions of invention;
- data are available for many countries and for long time periods.

The disadvantages of using patents as innovation indicators are:

- Patents indicate inventions and these may not become innovations;
- not all inventions are patented by firms due to the alternative of trade secrecy;
- some types of inventions cannot be patented;
- sectors vary in the intensity of use made of the patent system;
- some patents are used as a purely anticompetitive strategy;
- Different countries have stricter or looser regimes relating to patent awards.

What about trademarks?

Given this list of problems it is surprising that there have been few attempts to generate other types of data relating to intellectual property.

Specifically, the use of trademarks appears to have some potential and the following factors are relevant.

Registration of trademarks requires a fee to be paid, hence their registration signals a net expected value.

Trademarks are used extensively in every sector, whereas patents are dominated by the manufacturing sector.

Trademarks will be sought for more minor innovations than patents, such as new varieties of existing products, as there is no novelty test.

New and small firms are much more likely to use trademarks.

Desirable properties of innovation indicators

Feature	Description	Comments
Relevance	Serve the needs of actual and potential users	Innovation involves change, leading to changes in the needs of data users. Relevance can be reduced if potential users are unaware of available data or data producers are unaware of users' needs.
Accuracy/ validity	Provide an unbiased representation of innovation phenomena	There may be systematic differences in how respondents provide information depending on the collection method or respondent characteristics. Indicators can fail to capture all relevant phenomena of interest.
Reliability/precision	Results of measurement should be identical when repeated. High signal-to-noise ratio	Results can differ by the choice of respondent within a firm. Reliability can decline if respondents guess the answer to a question or if sample sizes are too small (e.g. in some industries).
Timeliness	Available on a sufficiently timely basis to be useful for decision-making	Lack of timeliness reduces the value of indicators during periods of fast economic change. Timeliness can be improved through nowcasting or collecting data on intentions. However, some aspects of innovation are structural and change slowly. For these, timeliness is less of a concern.

Desirable properties of innovation indicators

Feature	Description	Comments
Coherence/comparability	Logically connected and mutually consistent	
	Additive or decomposable at different aggregation levels	High levels of aggregation can improve reliability/precision, but reduce usefulness for policy analysis. Low levels of aggregation can influence strategic behaviour and distort measurement.
	Decomposable by characteristics	For example, by constructing indicators for different types of firms according to innovations or innovation activities, etc.
	Coherence over time	Use of time series data should be promoted. Breaks in series can sometimes be addressed through backward revisions if robustly justified and explained.
	Coherence across sectors, regions or countries, including international comparability	Comparability across regions or countries requires standardisation to account for differences in size or industrial structure of economies.
Accessibility and clarity	Widely available and easy to understand, with supporting metadata and guidance for interpretation	Challenges to ensure that the intended audience understands the indicators and that they "stir the imagination of the public" (EC, 2010).

Major resources for international innovation data using Oslo Manual Guidelines

Eurostat Community Innovation Survey (CIS) indicator database

Innovation indicators from the CIS for selected member states of the European Statistical System (ESS): http://ec.europa.eu/eurostat/web/science-technology-innovation/data/database.

Ibero-American/Inter-American Network of Science and Technology Indicators (RICYT)

Innovation indicators for manufacturing and service industries for selected Ibero-American countries: www.ricyt.org/indicadores.

OECD Innovation Statistics Database

Innovation indicators for selected industries for OECD member countries and partner economies, including countries featured in the *OECD Science, Technology and Industry Scoreboard*: http://oe.cd/inno-stats.

UNESCO Institute for Statistics (UIS) Innovation Data

Global database of innovation statistics focused on manufacturing industries: http://uis.unesco.org/en/topic/innovation-data.

The NEPAD (New Partnership for Africa's Development) for the African Union is also active in promoting the use of comparable indicators in Africa. Online links to this manual will provide up-to-date links to international and national sources of statistical data and indicators on innovation.

Methods for constructing innovation indicators

	Generic examples	Innovation examples
Types of indicators		
Statistical measures of frequency	Counts, conditional counts	Counts of product innovators
Measures of position, order or rank	Ranking by percentile or quartiles	Firms in the top decile of innovation expenditure distribution
Measures of central tendency	Mean, median, mode	Share of firms with a service innovation, median share of income/ turnover from product innovations
Measures of dispersion	Interquartile ranges, variance, standard deviation, coefficient of variation	Coefficient of variation presented for error margins, standard deviation of innovation expenditures
Indicators of association for multidimensional data		
Statistical measures of association	Cross-tabulations, correlation/covariance	Jaccard measures of co-occurrence of different innovation types
Visual association	Scatter plots, heat maps and related visuals	Heat maps to show propensity to innovate compared across groups defined by two dimensions
Adjustments to data for indicators		
Indicators based on data transformations	Logs, inverse	Log of innovation expenditures
Weighting	Weighting of the importance of indicators when constructing composite indicators, by major variables etc.	Indicators weighted by firm size or adjusted for industry structure
Normalisation	Ratios, scaling by size, turnover, etc.	Percent of employees that work for an innovative firm, etc.
Dimension reduction techniques		
Simple central tendency methods	Average of normalised indicators	Composite innovation indexes
Other indicator methods	Max or min indicators	Firms introducing at least one type of innovation out of multiple types
Statistical dimension reduction and classification methods	Principal component analysis, multidimensional scaling, clustering	Studies of "modes" of innovation, e.g. Frenz and Lambert (2012)

A Model for indicators on business innovation

To construct indicators, producers of innovation indicators can use answers to the following questions:

- What do users want to know and why? What are the relevant concepts?
- What indicators are most suitable for representing a concept of interest?
- What available data are appropriate for constructing an indicator?
- What do users need to know to interpret an indicator?

The relevance of a given set of indicators depends on user needs and how the indicators are used (OECD, 2010). Indicators are useful for identifying differences in innovation activities across categories of interest, such as industry or firm size, or to track performance over time. Conversely, indicators should not be used to identify causal relationships, such as the factors that influence innovation performance.

Indicators of innovation incidence and characteristics

General topic	Indicator
Product innovations	Share of firms with one or more types of product innovations
New-to-market (NTM) product innovations	Share of firms with one or more NTM product innovations (can also focus on new-to-world product innovations)
Method of developing product innovations	Share of firms with one or more types of product innovations that developed these innovations through imitation, adaptation, collaboration, or entirely in-house
Other product innovation features	Depending on question items, indicators can capture attributes of product innovations (changes to function, design, experiences etc.)
Business process Innovations	Share of firms with one or more types of business process innovations
NTM business process innovations	Share of firms with one or more NTM business process innovations
Method of developing business process innovations	Share of firms with one or more types of business process innovations that developed these innovations through imitation, adaptation, collaboration, or entirely in-house
Product *and* business process innovations	Share of firms with both product and business process innovations
Innovative firms	Share of firms with at least one innovation of any type
Ongoing/abandoned innovation activities	Share of firms with ongoing innovation activities or with activities abandoned or put on hold

Indicators of knowledge based capital/innovation activities

General topic	Indicator
Knowledge-based capital (KBC) activities	Share of firms reporting KBC activities that are *potentially related to* innovation
KBC activities for innovation	Share of firms reporting KBC activities *for innovation*
Expenditures on KBC	Total expenditures on KBC activities *potentially related* to innovation
Expenditures on KBC for innovation	Total expenditures on KBC activities *for innovation*
Innovation expenditure share for each type of activity	Share of expenditures for innovation for each of seven types of innovation activities
Innovation expenditures by accounting category	Total expenditures for innovation activities by accounting category
Innovation projects	Number of innovation projects
Follow-on innovation activities	Share of firms with ongoing follow-on innovation activities
Innovation plans	Share of firms planning to increase (reduce) their innovation expenditures in the (current) next period

Problems with international comparisons

International comparability between innovation indicators is limited by the following problems:

I. Differences in the design of surveys and questionnaires between countries
II. Characteristics of innovations, sectors and markets in different countries (context differences)

Composite indicators (scoreboards)

- The variety of indicators can complicate comparisons
- This suggested the construction of composite indicators, through the following two steps:
  - The Normalization of multiple indicators⇒Reduction of variety in measurement scales
  - Aggregation (weighed) of the normalized indicators

Composite indicators (scoreboards)

Advantages

- Reduction in the number of indicators
- Simplification towards and communication

Disadvantages

- The Limits in the theoretical bases (e.g. combinations of indicators of input and output)
- Subjective assignment of weights
- Standardization does not allow to adequately take into account structural differences (between countries)
- Loss of information (loss of detail)

Examples of innovation scoreboards and innovation indexes

OECD Science, Technology and Innovation (STI) Scoreboard

The *OECD STI Scoreboard* (www.oecd.org/sti/scoreboard.htm) is a biennial flagship publication by the OECD Directorate for Science, Technology and Innovation. Despite its name, it is closer to a dashboard. A large number of indicators are provided, including indicators based on innovation survey data, but no rankings based on composite indexes for innovation themes are included. Composite indicators are only used for narrowly defined constructs such as scientific publications or patent quality with weights constructed from auxiliary data related to the construct.

***European Innovation Scoreboard* (*EIS*)**

The *EIS* is published by the European Commission (EC) and produced by consultants with inputs from various EC services. It is intended as a performance scoreboard (see: http://ec.europa.eu/growth/industry/innovation/facts-figures/scoreboards_en). The *EIS* produces a hierarchical composite index (Summary Innovation Index) that is used to assign countries into four performance groups (innovation leaders, strong innovators, moderate innovators, modest innovators). The index uses a range of data sources, including innovation survey indicators. The European Commission also publishes a related *Regional Innovation Scoreboard*.

***Global Innovation Index* (*GII*)**

The *Global Innovation Index* (www.globalinnovationindex.org) is published by Cornell University, INSEAD and the World Intellectual Property Organization (WIPO). The *GII* is a hierarchical composite index with input and output dimensions that are related to different aspects of innovation. The *GII* aims to cover as many middle- and low-income economies as possible. It uses research and experimental development (R&D) and education statistics, administrative data such as intellectual property (IP) statistics and selected World Economic Forum indicators that aggregate subjective expert opinions about topics such as innovation linkages. The *GII* does not currently use indicators derived from innovation surveys.

The Use of an Innovation Index. Components of the European Innovation Scoreboard in 2020.

Many different innovation scoreboards have been created comparing firms, countries, and even cities. The basic method is to collate various different variables and then combine these into an index.

What is the European Innovation Scoreboard?

The annual European Innovation Scoreboard (EIS) provides a comparative assessment of research and innovation performance of EU countries, other European countries, and regional neighbours.

It allows policy-makers to assess relative strengths and weaknesses of national research and innovation systems, track progress, and identify priority areas to boost innovation performance.

The innovation indicators

The EIS 2020 follows the methodology of the 2019 edition in distinguishing between four main types of indicators and ten innovation dimensions, capturing in total 27 different indicators.

Framework conditions

Framework conditions captures the main drivers of innovation performance external to the firm and differentiates between three innovation dimensions:

- The Human resources dimension includes three indicators and measures the availability of a high-skilled and educated workforce. Human resources captures New doctorate graduates, Population aged 25-34 with completed tertiary education, and Population aged 25-64 involved in education and training.
- Attractive research systems includes three indicators and measures the international competitiveness of the science base by focusing on International scientific co-publications, Most cited publications, and Foreign doctorate students.
- Innovation-friendly environment captures the environment in which enterprises operate and includes two indicators - Broadband penetration among enterprises and Opportunity-driven entrepreneurship - measuring the degree to which individuals pursue entrepreneurial activities as they see new opportunities, for example resulting from innovation.

Investments

Investments captures investments made in both the public and business sector and differentiates between two innovation dimensions:

- Finance and support includes two indicators and measures the availability of finance for innovation projects by Venture capital expenditures, and the support of governments for research and innovation activities by R&D expenditures in universities and government research organisations.
- Firm investments includes three indicators of both R&D and non-R&D investments that firms make to generate innovations, and the efforts enterprises make to upgrade the ICT skills of their personnel.

Innovation activities

Innovation activities captures different aspects of innovation in the business sector and differentiates between three dimensions:

- Innovators includes three indicators measuring the share of firms that have introduced innovations onto the market or within their organisations, covering both product and process innovators, marketing and organisational innovators, and SMEs that innovate in-house.
- Linkages includes three indicators measuring innovation capabilities by looking at collaboration efforts between innovating firms, research collaboration between the private and public sector, and the extent to which the private sector finances public R&D activities.
- Intellectual assets captures different forms of Intellectual Property Rights (IPR) generated in the innovation process, including PCT patent applications, Trademark applications, and Design applications.

Impacts

Impacts captures the effects of firms’ innovation activities and differentiates between two innovation dimensions:

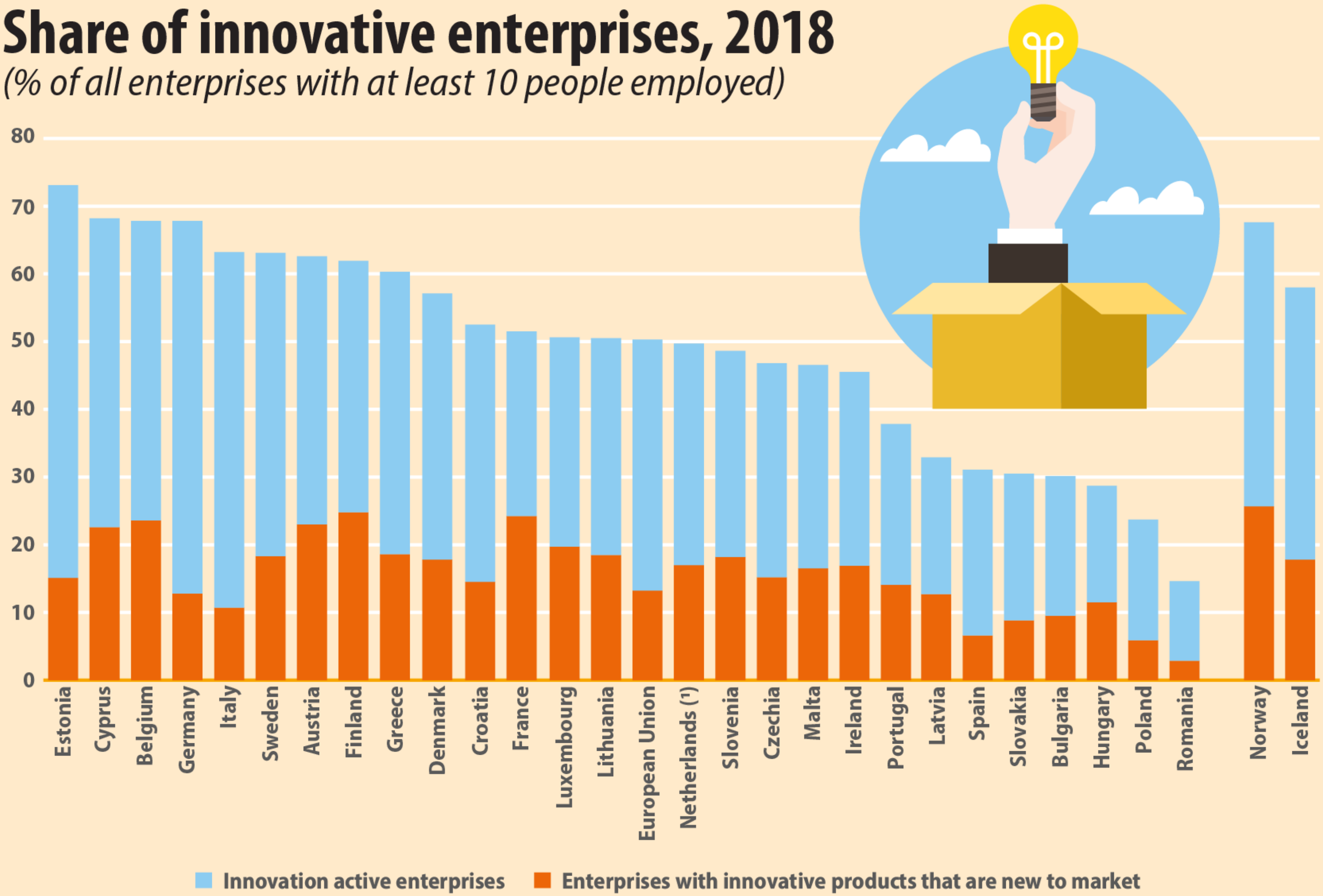
- Employment impacts measures the impact of innovation on employment and includes two indicators measuring Employment in knowledge-intensive activities and Employment in fast- growing firms in innovative sectors.
- Sales impacts measures the economic impact of innovation and includes three indicators measuring Exports of medium and high-tech products, Exports of knowledge-intensive services, and Sales due to innovation activities.

Enterprises with innovation activities during 2016 and 2018

GEO (Labels)	Innovative enterprises	Enterprises with completed innovation activities	Enterprises with abandoned/suspended innovation activities	Enterprises with on-going innovation activities
European Union - 27 countries (from 2020)	50.3	45.4	7.4	26.2
Euro area - 19 countries (from 2015)	56.0	51.3	8.8	30.8
Germany	67.8	63.7	9.0	35.2
Spain	31.1	28.8	2.7	10.7
France	51.5	49.0	6.9	28.1
Italy	63.2	56.7	13.8	47.6
Netherlands	49.7	46.2	8.4	23.6
Austria	62.6	60.3	6.7	19.3
Finland	61.9	55.7	10.6	28.7
Sweden	63.1	61.4	2.5	27.2

Share of innovative enterprises, 2018

(% of all enterprises with at least 10 people employed)



(¹) Definition differs (see footnotes)

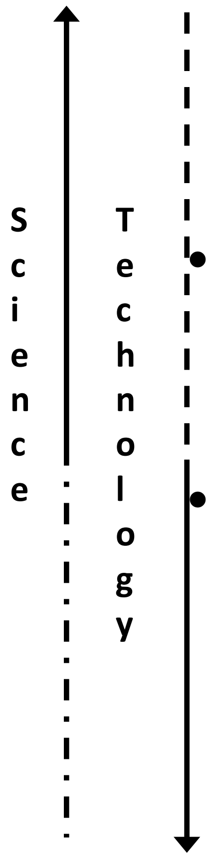
R&D

It is possible to extend the discussion on R&D.

Focusing on national trends, industry breakdowns and specific firms

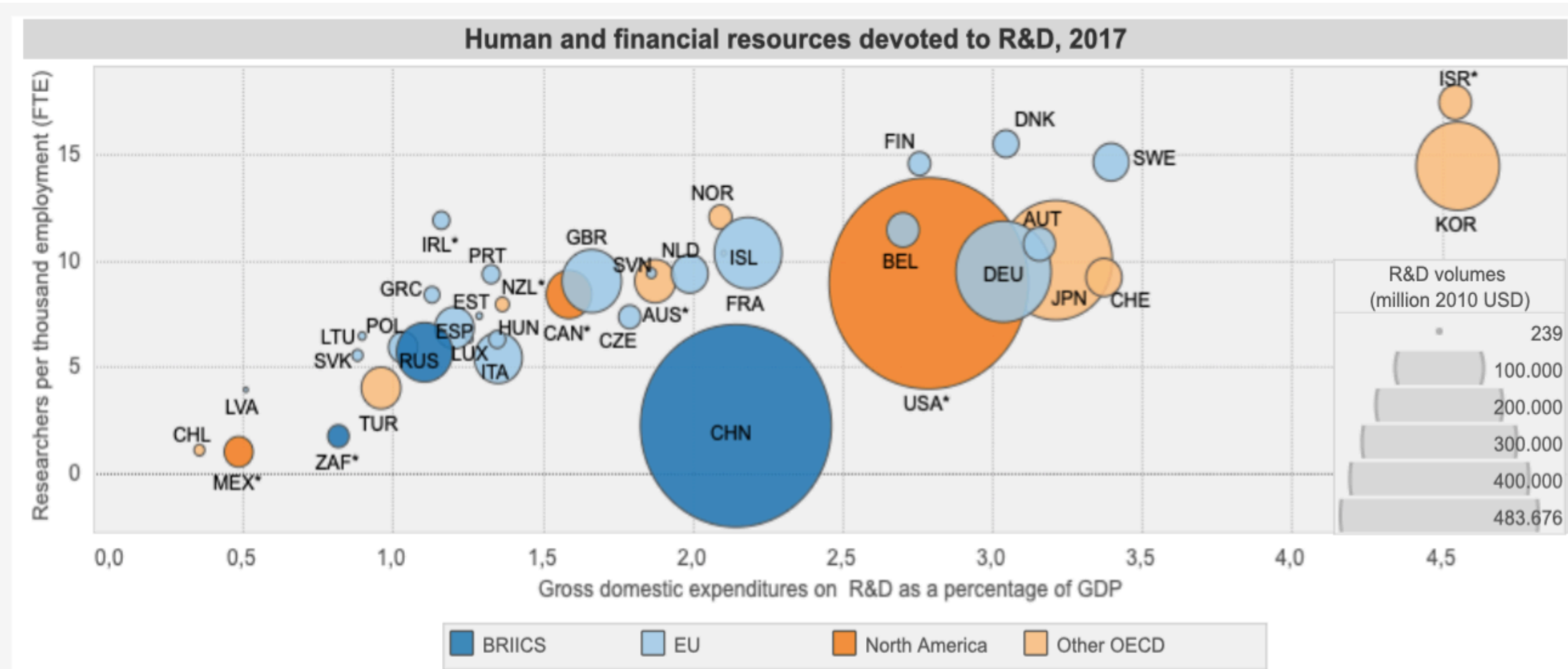
- In most countries there are a few major companies that dominate absolute amount, but amount done by smaller companies may be very important for future growth
- Specific R&D policies
- Problems of compiling real R&D measures and cross country measures

R&D – (OECD Frascati Manual)



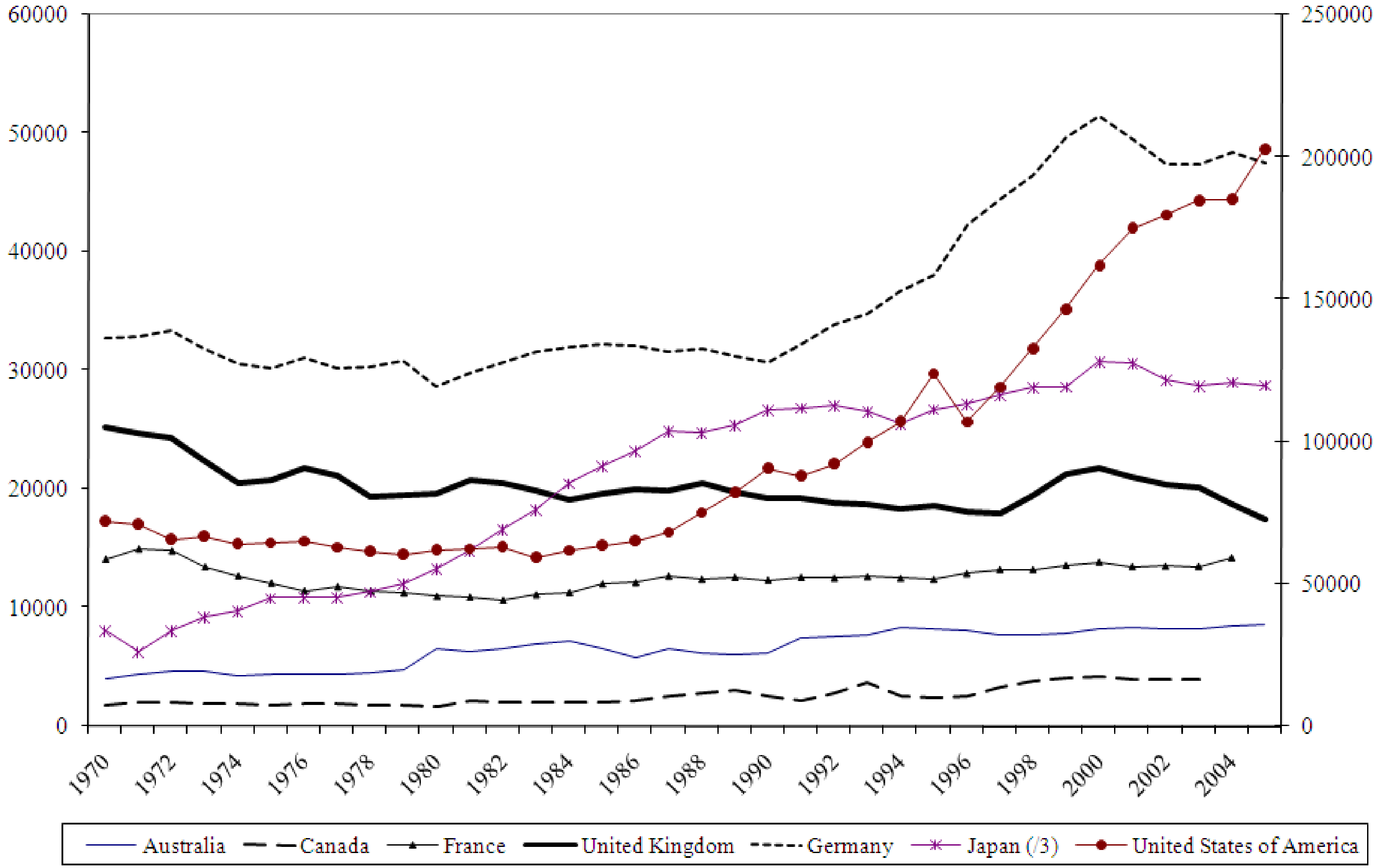
- **Basic Research**: experimental/ theoretical work undertaken primarily to acquire new knowledge of the underlying foundations and phenomena and observable facts, without any particular application or use in view
- **Applied Research**: original investigation undertaken in order to acquire new knowledge , directed primarily towards a specific practical aim or objective
- **Experimental Development**: systematic work, drawing on existing knowledge gained from research and practical experience, directed to producing new materials, products and devices; to installing new processes, systems or services; to improving substantially those already produced or installed.

Human and financial resources devoted to R&D

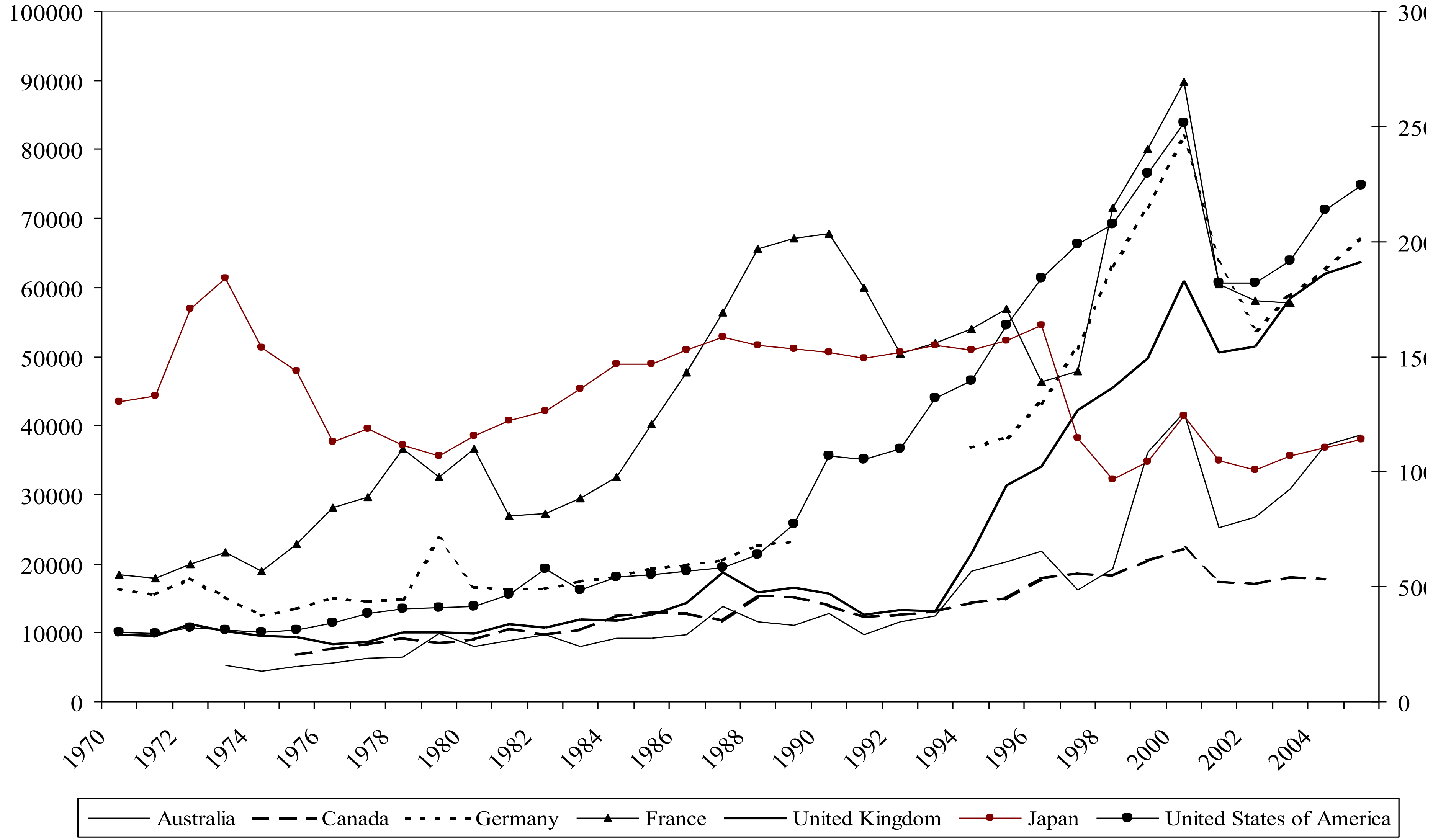


Source: OECD, Main Science and Technology Indicators Database, http://oe.cd/msti , July 2019.

Patent applications by domestic residents by country (RH scale: US & Japan)



Trademark applications by domestic residents by country (RH scale: US & Japan)



Other economic growth resources

- There is a vast amount of productivity and economic growth data on web that could be used to look at specific countries, periods or industries e.g.
  - National statistical agencies
  - World Bank, OECD (includes regular country studies), IMF
  - The Groningen Growth and Development Centre
  - Penn World Table

Productivity and growth

To measure real output we use value added:

- *Value added* is defined as sales minus raw materials used
- It indicates what the firm has truly produced when transforming the raw materials into the final product
- Both sales and raw materials have to be deflated for any price inflation when measuring over time

Definitions of *partial factor productivity*:

- labour productivity (value added per unit of labour)
- capital productivity (value added per unit of capital)
- High labour productivity is often largely explained by high levels of capital per worker (e.g. in mining and the steel industry)
- High capital productivity will be present when labour is used intensively (e.g. in developing countries with scarce capital)

Measuring total factor productivity

- This measure improves on partial factor productivity by correcting for growth in inputs
- Derivation of total factor productivity:

  Suppose value added (Y) is produced by two input factors capital (K) and labour (L) and by total factor productivity (A) according to:

$$Y = A\,K^{\alpha}\,L^{\beta}$$

- Then growth of TFP is calculated by residual:

$$g_A = g_Y - \alpha\, g_K - \beta\, g_L$$

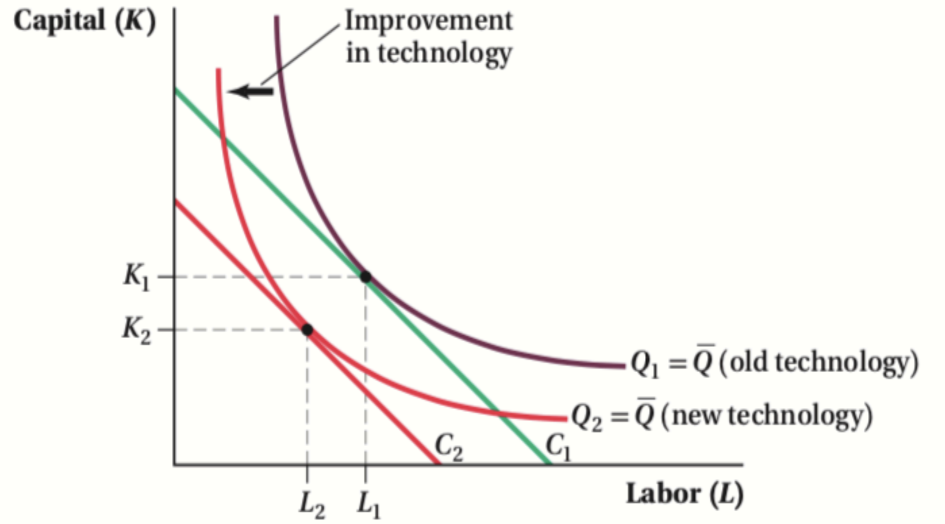
- Growth in TFP is equal to the growth in value added, less α times the growth in capital input and β times the growth in labour input

Total factor productivity growth (or technological change)

An improvement in technology that changes the firm’s production function such that more output is obtained from the same amount of inputs.

The impact of technological change

An improvement in technology shifts the isoquant $Q_1 = \bar{Q}$ inward to $Q_2 = \bar{Q}$. The new cost minimizing input combination (L_2,K_2) is located at the tangency between Q_2 and the isocost C_2. (L_2,K_2) uses fewer inputs and is, therefore, cheaper than the original cost-minimizing input combination (L_1,K_1) located at the tangency between Q_1 and the isocost C_1.



Quality adjustments and difficulties in measuring output growth. Case: the light

A good way to understand the issues is to consider how the price, and output, of light has varied since 1800.

Nordhaus (1998): “Quality change in price indexes.”

- As technology has changed—from candles, to oil lamps, to electric lightbulbs—the “output” of light has grown dramatically. The true output can be measured in lumens per hour; hence it is possible to calculate how much one lumen-hour cost over time.
- statistical agencies have also recorded the prices of candles, lamps, and electric lightbulbs. These prices are used to calculate the official price index for light over time.
- Nordhaus finds that there is a massive difference between the official and true series, with the official price series hugely overestimating the price of light. This is because the official, or conventional, series does not take account of the substantial technological changes that have raised the number of lumens per dollar spent on lighting.
- How much is the difference between the conventional and true indices?
- Nordhaus (1998) states that “The conventional price of light has risen by a factor of about 1,000 relative to the true price” over the 1800–1992 period.

Quality adjustments and difficulties in measuring output growth. Case: the computers

Another good example comes from the ICT sector and, in particular, measuring the output of computers.

- Over the last twenty years new computers have increased in speed, memory size, portability, and quality at a rapid rythm. At the same time the price paid for a computer has fallen.
- Using only the total sales of computers will underestimate the true value of computers. It would be better to adjust the price of a computer to reflect the true value that it represents compared with previous models. This adjustment process is made in a number of countries, such as the United States, France, and Denmark, but not in all OECD countries. Specifically, the method often used is a so-called hedonic price index. This is a method that evaluates the value associated with each aspect of a computer's performance, such as processor speed and memory.
- The method involves running a regression of the log of price (*P*) on the log of speed (*S*) and memory (*M*) plus other characteristics—call these *X*:

$$\ln(P) = a_0 + a_1\ln(S) + a_2\ln(M) + a_3\ln(X) + e.$$

The coefficients a_1, a_2, and a_3 then give a method of assessing the true price of a new computer with new levels of speed and memory. This, in turn, can be used in a variety of ways to produce a price index that produces a more accurate picture of technological, or quality, changes across time. The fact that different countries use different techniques implies that cross-country comparisons of ICT sectors should be treated with caution.

Comparing Productivity and Growth across Countries

GDP per capita can be decomposed into separate component:

$$GDPpc = \frac{GDP}{population} /= [(\frac{GDP}{hours}) \times (\frac{hours}{workers})] x \frac{workers}{population}$$

- GDP per hour, is a measure similar to the labor productivity measures.
- Hours per worker, simply informs us how much, on average, workers are at work rather than at leisure.
- The ratio of workers to reflects the fact that in any society there are those too young or too old to work; there are also those in tertiary education or physically unable to work; there are also unemployed workers.

Annual average growth in GDP per hour worked (1970-2006)

	Australia	Canada	France	Germany	Italy	Japan	UK	US
1970-1980	1.5	1.8	4	3.7	4	4.2	2.7	1.6
1980-1985	2.2	1.6	3.1	2.1	1.2	2.5	2.5	1.6
1985-1990	0.2	0.4	2.7	2.5	2.3	4.2	1.4	1.3
1990-1995	2	1.4	1.9	2.9	2.1	2.3	2.8	1.1
1995-2000	2.5	2.3	2.1	2	0.9	2.1	2.3	2.2
2000-2006	1.5	1	1.4	1.4	0.2	2.1	2	2.1
1970-2006	1.6	1.5	2.7	2.6	2	3	2.3	1.7

Average growth of GDP per capita in emerging markets

	Brazil	China	India	Japan	Korea	Taiwan	Thailand
1951-1960	3.93	4.11	1.57	7.54	1.03	4.44	-0.15
1961-1970	4.34	1.45	2.69	9.74	5.82	7.04	5.07
1971-1980	5.38	4.18	1.61	3.18	5.93	7.75	4.62
1981-1990	0.21	8.43	3.48	3.43	7.90	6.59	6.08
1991-2000	0.53	9.15	3.41	1.01	5.19	5.49	3.03
2001-2004	0.09	7.44	4.19	0.72	4.09	2.16	3.97