Australia's National
Science Agency

Science, Technology and Innovation Indicators

Aus4Innovation

Policy Exchange Activity 3 (PE3)

Supporting the development of Vietnam's Science Technology and Innovation Strategy 2021-30

December 2020

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1 Executive summary

This report provides a general overview of science, technology and innovation (STI) indicators and recommendations for the collection of STI indicators for Viet Nam.

STI indicators measure, where relevant, the **inputs**, **activities**, **outputs** and **outcomes** of science, technology and innovation. The focus of science indicators is on the creation of new knowledge, as measured by R&D, bibliometrics, patent statistics, or the supply of scientists and engineers, while indicators for innovation focus on the commercialization of technologies (broadly defined).

STI indicators need to clearly distinguish between science and technology, on the one hand, and innovation on the other hand. While science and technology differ, there is a continuum between them, in the sense that technology often depends on science and applied research can lead directly to new technology. Conversely, there is an important conceptual difference with innovation, which requires the *implementation* of new or improved products or processes. With a few exceptions, such as technology licensing that can produce income for the licensee, the economic and social benefits of science and technology require their use in practical applications (ie. innovation).

The majority of economic activity is in low and medium technology manufacturing and service sectors that can benefit substantially from innovation activities. Consequently STI policy needs to address STI activities of relevance to high, medium and low technology sectors.

Policy needs to differentiate between 'ST' indicators and 'I' indicators. Science and technology policy concerns the creation of new knowledge, while innovation policy focuses on improving the innovation capabilities of businesses, while ensuring that they are still competitive and profitable. Innovation is required to turn new knowledge into economic and social benefits.

High quality STI indicators can be used for benchmarking, such as progress towards a policy target, and to inform the development of new policy and changes to existing policy. Indicators at the micro level of the business or institution can also be used in academic research on the factors that support or hinder outputs or outcomes. Many indicators that are collected on a regular basis over time can be used to track developments in targeted technologies or industries, as long as data are available for specific sectors of interest. Indicators derived from surveys need to be representative of the population of interest, which requires either a census or random sampling and low error rates. Best practice requires survey questions to ask respondents about events for which they have direct knowledge (for instance their business's experience with government policies on technical change).

Most STI indicators are constructed from administrative or survey data. An alternative is the use of 'big data' sources, such as the internet or data collected by devices such as smartphones. The main methodology is data mining by web-scraping bots that use textual analysis to identify innovation activities that are posted on websites. However, web-scraping methods substantially underestimate innovation activities.

International expertise and experience with STI indicators is summarized in Table 2. Indicators have been developed for 13 categories: human resources, R&D, bibliometrics and patents / design registration, entrepreneurship, knowledge transfer, demand, capital expenditures, trade, digitalization, innovation, environmental innovation, and public sector innovation.

In respect to STI indicators and policy, economies can be divided into two main sectors: 1) the research and training sector (primarily universities, research institutes, and other tertiary training institutions) that produces new knowledge and skilled people who can develop and apply knowledge to the creation of new goods and services and 2) sectors that use existing and new knowledge and technology to produce goods and services (SOEs, private businesses, and governments). A third requirement is for indicators for knowledge exchange, both within and between the two main sectors.

STI indicators need to capture inputs, activities, outputs and outcomes within each sector and knowledge exchange between the two sectors and with organisations abroad. Of crucial importance, indicators are required for both **quantity** and **quality**. For instance, indicators of research outcomes must cover not only the number of publications, but also the quality of publications.

The production of STI indicators requires the following types of data or surveys:

1. R&D survey of businesses and public research organisations
2. Data for student graduation rates, plus supplementary data on post-graduation employment. This may be available from administrative records kept by universities and other tertiary education institutions.
3. Surveys of the knowledge transfer activities of public research organisations. These can usually be addressed to the knowledge transfer office (KTO) affiliated to each university or research institute.
4. Innovation survey of businesses, SOEs and possibly public sector organizations.
5. Labour force survey.

The collection of indicators over time can be used to assess progress towards pre-defined targets. Baseline and other types of data are required to set targets. When no data are available, it is sometimes possible to set an approximate target based on experience in other countries.

Almost all types of indicators can be disaggregated to collect data for priority sectors or research fields, but this requires collecting the necessary data at a granular level. Collecting data for the business sector on the use of and research into generic technologies that span multiple sectors, such as biotechnology or artificial intelligence (AI), requires customized surveys (technology use surveys) that focus on specific fields of science.

Recommended indicators for Viet Nam are provided in Table 6 for the research and training sector, Table 7 for the goods and services producing sectors, and Table 8 for knowledge exchange. Due to a lack of baseline and other data, the tables usually only describe the type of target and the rationale for the target. These include indicators of relevance to the following areas:

- The start-up ecosystem
- The share of enterprises with innovation activities
- Foreign investment in R&D and innovation
- Technology acquisition from international sources
- Linkages between businesses and research institutes / universities
- S&T based enterprises
- Capabilities in priority technologies
- Capabilities of the public research and training infrastructure
- Capabilities of public research to respond to market demand
- Capabilities of the organizations producing goods and services
- Management of S&T and innovation
- Digital transformation
- Network of intermediary and knowledge transfer organisations
- Restructuring of service industries
- Adoption of high technology in manufacturing and other sectors

2 Introduction

This report provides a general overview of science, technology and innovation (STI) indicators and recommendations for the collection of STI indicators for Viet Nam.

Part 1 covers definitions, indicator quality and issues with misuse, the options for using big data to create STI indicators, how indicators can support policy, and the types of indicators that have been developed and used internationally and within specific countries of interest. Section 2.3 describes 13 general categories of STI indicators that have been developed and published by international organizations. These represent the current state-of-the-art for innovation indicators. Section 2.4 describes the types of STI indicators that are in current use in selected countries, including Australia, China, and the Republic of Korea and gives examples of the use of detailed indicators for one major policy area of interest: knowledge transfer from universities and public research institutes to businesses.

Part 2 provides recommendations for the collection of STI indicators to support policy priority areas for Viet Nam. These are divided into three general types of indicators, based on policy focus areas. Section 3.1 covers indicators for the public research and training sector (universities and public research institutes), section 3.2 covers sectors that produce goods and services (primarily governments and private businesses), and section 3.3 covers knowledge exchange, both within and across sectors.

3 PART 1: Overview and International Experience with STI Indicators

An indicator is a statistic that has been standardized in some way in order to permit comparisons. An example of a statistic is a count of the number of patents granted in Viet Nam. An indicator is the number of patents granted in 2019, which permits comparison with the number of patents granted in 2009. An indicator for the number of 2019 patents per million inhabitants permits comparisons with other countries. Statistics, and consequently indicators, are obtained through measurement.

Measurement requires clear definitions that distinguish between activities or characteristics that are part of the concept to be measured and activities or characteristics that need to be excluded. There is likely to be little measurement error in indicators obtained from administrative data (obtained from governments or authorities, usually for reasons that have nothing to do with creating STI indicators). For instance, a count of the number of patents granted in a defined period is based on the decision of a patenting authority on whether or not to grant a patent. However, errors can occur in patent data when creating patent indicators for specific sub-groups. For instance, a small amount of error can occur when counting the number of patent grants for universities or businesses because errors can be made in the type of applicant – analysts could misclassify a patent to a university as a patent to a business and vice versa.

Inclusion and exclusion errors can occur when respondents to a survey do not fully understand survey questions. For instance, data on R&D are obtained through surveys of managers or accountants at businesses, universities, and government agencies. Errors in the data for R&D will occur if some of the responding individuals do not clearly understand the boundary between activities that are and are not part of R&D. As this boundary is difficult to define (OECD, 2015), it is inevitable that error will occur in indicators for R&D activities such as R&D expenditures in the business or government sectors. Some respondents will include activities that are not part of R&D, while other respondents (or the same respondent) could exclude activities that are part of R&D. The more serious issue is inclusion errors that occur when many respondents do not understand a concept. This creates an important limitation to the types of questions that can be asked in a survey.

There is a common misconception that all administrative data have very low error rates, but this is due to a 'black-boxing' phenomenon whereby data users ignore the metadata that describe how the original data were collected.

3.1 Definition of Science, Technology and Innovation

Science involves the development and testing of theories to describe the structure and behaviour of the natural and social worlds. A common measurement of science activities is basic research, defined by the Frascati Manual[1] as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view". Some science activities are also captured by applied research, defined on the same page of the Frascati Manual as "original investigation undertaken in order to acquire new knowledge" …and "directed primarily towards a specific, practical aim or objective".

Technology consists of the practical use of scientific discoveries, such as the "use and application to

[1] OECD 2015, p. 29

business processes or products of technical methods, systems, devices, skills and practices".[2] This includes organizational and process methods, including software, based on systems rather than on physical goods. Technology can be produced through systematic R&D, through experimental development[3], or without the use of R&D at all.

The OECD's series of Oslo Manuals define innovation and provides guidelines for the measurement of innovation. The fourth edition of the Oslo Manual defines innovation as "a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)".[4] Products include goods and services, while processes include both technological processes and non-technological processes such as organizational innovations and some types of administrative and business model innovations.

The OECD definition requires an innovation to be novel (differs significantly from what was used or available before) and to be implemented (made available to users or used by the unit). Chapter 3 of the fourth edition of the Oslo Manual clarifies that the concept of novelty ('significantly different') is from the perspective of the business. What is considered to be a significant difference for a small business is likely to differ from that for a large business. Furthermore, a business does not need to develop an innovation itself. The Oslo Manual (p. 70) states "many innovations are based on purchasing, imitating or modifying products, business process equipment, or business methods that are already in use by other businesses or organizations".

The OECD definition of innovation is expansive, capturing both incremental innovations and radical or disruptive innovations that require substantial investment in R&D. In contrast, many uses of the term 'innovation' focuses on advanced technology built on R&D, such as applications of artificial intelligence or breakthrough pharmaceuticals. The OECD definition is intentionally expansive because the goal is to measure activities that increase productivity and well-being. Meeting these goals requires technology and systems that improve productivity and well-being to diffuse throughout an economy, as when farmers innovate by adopting new planting techniques that conserve water and fertilizer, by hotels that innovate by taking part in online booking systems, or by small shop owners that innovate by adopting software to track their inventory.

An important aspect of the definition of innovation is that an innovation is defined by time - something that is novel is not novel forever. The Oslo Manual recommends that the observation period during which an innovation and innovation activities occur should be no less than 1 year and no more than 3 years. In Australia, innovation survey respondents are asked about new products or processes that their business introduced within the previous year, whereas in most European countries they are asked about new products or processes within the previous three years. The length of the observation period is a key part of the definition of an innovation and of innovation activities. For example, innovation activities that are infrequent are more likely to be identified when the observation period is three years than when it is one year. This particularly affects small and medium-sized enterprises (SMEs), which are less likely than large businesses to collaborate, develop an innovation, apply for a patent, or have expenditures on training or marketing for innovation within a one year observation period.

[2] OECD/Eurostat, 2018, p.117.

[3] Experimental development is defined as "systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes". OECD 2015, p. 29.

[4] OECD/Eurostat, 2018, p.60.

STI indicators measure, where relevant, the **inputs**, **activities**, **outputs** and **outcomes** of science, technology and innovation. The focus of science indicators is on the creation of new knowledge, as measured by R&D, bibliometrics, patent statistics, or the supply of scientists and engineers, while indicators for innovation focus on the commercialization of technologies (broadly defined).

> **Inputs** cover all resources that are used for an activity such as science or innovation. Inputs for science include expenditures on equipment and wages and the amount and type of human capital involved.
>
> **Activities** cover how resources are combined and used. For instance, human and financial resources can be combined in a collaboration between several businesses and universities to address a problem.
>
> **Outputs** are the immediate effect of activities. For science activities, commonly measured outputs are discoveries, patents, and peer-reviewed publications. The outputs of the innovation activities of businesses consist of specific types and numbers of innovations.
>
> **Outcomes** are most relevant to innovation and consist of the micro level effects of innovation activities on a business or government organization (increase in sales, efficiency or profits; satisfaction of clients, etc.), meso level effects for an industry (value added of exports), and macro level effects on the economy (increased per capita average or median income), or society (better quality of health care and the health status of a population). Outcomes can sometimes be observed for science and technology, for instance a university can earn income from licensing a discovery to a business. Outcomes are considerably more difficult to measure than inputs, activities and outputs because of the difficulty in attributing outcomes (such as a change in business revenues) to innovation.

STI indicators need to clearly distinguish between science and technology, on the one hand, and innovation on the other hand. While science and technology differ, there is a continuum between them, in the sense that technology often depends on science and applied research can lead directly to new technology. Conversely, there is an important conceptual difference with innovation, which requires the *implementation* of new or improved products or processes. A business can purchase new technology and never implement it, or a business can produce patents that are never used. Neither will have an economic effect (other than economic losses). With a few exceptions, such as technology licensing that can produce income for the licensee, the economic and social benefits of science and technology require their use in practical applications (ie. innovation).

Table 1 summarizes the types of data that can be used to measure the inputs, activities, outputs and outcomes for science, technology, and innovation. Further details on the data are provided below in Table 2.

Table 1 Data types for measuring inputs, activities, outputs and outcomes

	Science	Technology	Innovation
Inputs	Basic & applied R&D expenditures, human resources	Experimental development R&D, human resources	R&D, skilled human resources, capital investments in machinery & equipment, Venture Capital

Activities	Research projects including contractual and collaborative projects with businesses, R&D expenditures by field, patents by field	Research projects, patents by field	Collaboration, external knowledge sourcing, use of design thinking and co-creation, response to demand for innovation (procurement, etc.)
Outputs	Invention disclosures, bibliometrics, patents	Patents, industrial designs	Number or types of innovations (product, process)
Outcomes	License income from IP	License income from IP	*Micro*: Sales share of innovations, change in cost per unit of production, change in profits, reduction in harmful emissions *Meso*: change in value-added of exports *Macro*: environmental effects, change in social conditions (health, well-being, income, etc.)

3.1.1 Innovation and diffusion

The economic and social benefits (or costs) of innovation depend on diffusion processes whereby an innovation is adopted by hundreds or thousands of businesses or, in the case of consumption goods, by millions of individuals. A new product that substantially reduces CO^2 emissions (an electric vehicle perhaps) will have little effect on total CO^2 emissions if very few people or businesses replace their diesel or petrol vehicles with an electric vehicle. Innovation in many industries, such as low and medium-technology manufacturing, and in the household sector is strongly based on diffusion processes. An influential European report from 2006 noted " making innovation work means innovation capacity building, the uptake of new technologies and of existing technologies in a new context and carrying them through to the business level."[5]

The invention and commercialization of new products and processes is more characteristic of 'high technology' manufacturing sectors such as ICT or pharmaceuticals, although these sectors will also depend on diffusion for many of their innovations, for instance in manufacturing processes or organizational methods. The importance of innovation through diffusion in many industries means that a policy focus on high technology manufacturing or services can have little economic or social impact, unless the products of high technology sectors are exported or broadly diffused within the economy.

In many countries high technology sectors account for only a few percentage points of national GDP. Instead, ostensibly 'low' and 'medium' technology sectors account for the majority of the output and employment of the business sector. Businesses in low and medium technology manufacturing and service sectors can benefit substantially from innovation activities such as adopting and learning how to use new technology, in-house modifications and continuous improvements to their goods, services and processes; or from adopting or developing new organizational methods and business models.

[5] CEC, 2006.

Economic development frequently depends on innovation by businesses in low and medium technology sectors.

3.1.2 Indicator relevance, quality and misuse

Many indicators that purport to measure innovation do not do so. For instance, almost all of the indicators in the Global Innovation Index [6] are not indicators of innovation, but of framework conditions, science and technology, or potential inputs to innovation. There are only a few indicators for innovation activities (5.2.1 on university-industry collaboration, 5.1.3 on GERD performed by businesses), one indicator for innovation outputs (7.1.2 on industrial designs) and no indicators for innovation outcomes in the business sector.

Other common indicators, such as patents, are often treated in the academic and policy literature as measures of innovation. They are not – patents measure a specific type of science and technology output. They are also potential inputs to innovation.

It is also important to carefully assess the value of innovation indicators. An example is the percentage of businesses in a country or sector that innovate, derived from responses from innovation surveys based on the Oslo Manual.[7] This is a low value indicator because of the wide definition of innovation used in these surveys, which includes everything from adopting technology or ideas in use by other businesses to an innovation based on R&D. In addition, survey data need to be used to identify the percentage of businesses within a sector (or by size class) that have different innovation capability profiles.[8] For instance, it is possible to identify the percentage of businesses that only innovate through adoption, those with the capabilities to modify purchased technology to meet their own needs, and those that can create entirely new innovations through R&D.[9]

Another common error in the use of indicators is to assume that more is always better – for instance higher R&D intensity is better than lower R&D intensity, or that more patent applications by universities is always better than a smaller number of patent applications. In contrast, high levels of R&D intensity are only likely to be beneficial in specific sectors such as pharmaceuticals or aerospace. High average R&D intensities across a sector, such as for all businesses active in food manufacturing or retail services, are likely to indicate misguided investment or a failure to apply R&D results to a high volume of goods and services.[10] For universities, and very poor and misleading indicator is the number of patent applied for or granted in a defined time period. What counts is the share of patents that are licensed to businesses or other organizations that can usefully apply the knowledge in the patent.

3.2 Policy and Indicators

Policy needs to differentiate between 'ST' indicators and 'I' indicators. Science and technology is a comparatively easy target for policy because the main policy tools are under the direct control of government. For instance, government determines the level of support for R&D and training in the

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[6] Cornell University et al, 2019.

[7] A similar indicator is computed for Viet Nam, using the NASATI innovation survey of 2017-2018.

[8] OECD/Eurostat, 2018, p 82. Part 2 of this report on indicator recommendations will describe how to construct relevant indicators from innovation surveys.

[9] See Arundel and Hollanders, 2005, for an example.

[10] There are always individual businesses that are commercially successful exceptions. For instance, high R&D intensities could be observed in food manufacturing businesses that produce high-value flavourings such as vanilla through biotechnology.

public research and training sector (universities and public research institutes), R&D grants and incentives for businesses to conduct R&D, and the rules and incentives governing knowledge exchange between businesses and the public research and training sector. The constraints on investment in science and technology by government are the financial costs to the government and the opportunity costs.

The policy response for innovation largely concerns improving the innovation capabilities of businesses, while ensuring that they are still competitive and profitable. This places an important constraint: businesses that increase their investment in innovation inputs and activities are likely to increase their capabilities, but this is not sustainable without a subsequent increase in competitiveness. From a business perspective, innovation must be profitable. From a government perspective, policies to support business innovation run the risk of favouring some businesses over others, misappropriation of funds by businesses, and policy capture by influential businesses. All could reduce competition.

Compared to policies to support S&T, such as R&D tax incentives and grants, policies to support innovation capabilities are less costly, but require careful application. Common innovation policies include support for the commercialization of publicly-funded R&D in universities and research institutes, providing training to the staff of SMEs in technology requirements and innovation management, technology adoption subsidies, such as for modernization; subsidies to acquire licenses to new technology, subsidies to hire skilled science and engineering graduates, and extension services to help businesses identify appropriate new technologies.[11]

Given the distinct differences between science and technology in comparison to innovation, and the different policies to address each of them, a basic requirement for STI indicators is to obtain relevant indicators on science and technology *and* on innovation. As suggested by the almost complete lack of innovation indicators in the Global Innovation Index, this is not an easy task. The main hurdle is the cost of producing high-quality innovation indicators, which often requires expertise in surveys.

3.2.1 Indicators for sectors of interest

Many indicators that are collected on a regular basis over time can be used to track developments in targeted technologies or industries, as long as data are available for specific sectors of interest. However, tracking the development of emerging, generic technologies such as biotechnology, zero carbon energy or AI create unique problems for indicators because these technologies do not match existing industry classification systems. For instance, there is no single 'biotechnology' or 'artificial intelligence (AI)' industry. AI can be developed and used by businesses active in internet services, ICT, manufacturing, health services and many other industries. Since generic technologies have applications in many industries, it is often necessary to design data collection methods that identify relevant investments in R&D, applications and innovations in multiple industries or fields of science, using specialized surveys or customized analyses of patent databases, trade records, venture capital investments, etc. An alternative is to use web-scraping methods to identify businesses active in AI applications (see section 2.6 below).

3.2.2 2.2.2 Criteria and coverage for indicators

High quality STI indicators can be used for benchmarking, such as progress towards a policy target, and to inform the development of new policy and changes to existing policy. Indicators at the micro

[11] Arundel et al, 2007.

level of the business or institution can also be used in academic research on the factors that support or hinder outputs or outcomes.

There are several criteria for producing good quality, useful indicators[12]:

- Based on high-quality statistics that are representative of the population of interest.
- Constructed using robust analytical principles.
- Available at regular intervals over time (necessary for benchmarking).
- Relevant for policy.

Statistics derived from surveys need to be representative of the population of interest, which requires either a census or random sampling and low error rates due to well-designed questions.[13] The response rate should be high (>80%) to reduce possible biases. When the response rate is lower, non-respondent comparisons or follow-up surveys are required to determine possible response bias.

A general picture of events is then constructed by taking the average for responses from a representative sample of business managers.

Due to limited data availability, compilations of STI indicators in scoreboards and other reports sometimes use data derived from expert opinion surveys. The World Economic Forum *Global Competitiveness Reports* include many indicators based on comparatively small samples of executives, who are asked their opinion on conditions "in your country". For example, the 2019 report gives results for the question "In your country, to what extent does the government respond effectively to change (e.g. technological changes, societal changes, societal and demographic trends, security and economic challenges)?[14] This does not meet the requirement for 'robust analytical principles' because respondents are asked questions about events for which they may have no personal experience. Nevertheless, compilations sometimes use a small number of indicators drawn from the Expert Opinion Survey (EOS) of the WEF when no other data sources are available. For example, the Global Innovation Index uses five EOS indicators for innovation: university-industry research collaboration, intensity of local competition, state of cluster development, ICT and business model development, and ICT and organizational model creation.[15]

There is a frequent conflict between the availability of STI indicators and policy requirements that is particularly acute for innovation indicators. The Global Innovation Index, for instance, only includes indicators that are available for most of the world's 200 plus countries. Innovation indicators are excluded because they are only available for a small number of countries (and in some cases replaced with EOS data). The OECD's 2019 Innovation Indicators report provides data for 36 innovation indicators, but these are only available for 38 countries, all of which conduct innovation surveys of

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[12] See, in part, OECD STI Scoreboard, 2017, p 3. (http://www.oecd.org/sti/oecd-science-technology-and-industry-scoreboard-20725345.htm) and chapter 9 of the 4th edition of the Oslo Manual.

[13] Survey questions should undergo cognitive testing, which is the gold standard for question design that is used by national statistical organizations such as the ABS in Australia, Statistics Canada and INSEE in France. All changes and additions to questions in the European CIS are cognitively tested. Cognitive testing involves interviews with respondents drawn from the target population for a survey or census. Each question is tested to determine if the interviewees understand the question as intended and can give a reasonably accurate response. A description of cognitive testing is provided by Willis, 2004.

[14] Schwab, 2019, p. 616. The average sample of expert respondents per country is 97.5, but results for two consecutive years are averaged (with some weighting on the second year) to increase the sample size.

[15] Global Innovation Index 2019, p 349.

businesses.[16] Only three of these 38 countries (China, Columbia, and Turkey) are not high-income countries as defined by the UN.

Indicators are often provided at the national level, but for policy purposes indicators need to be available at different levels of disaggregation, for instance by geographical area for policies to support regional economic development, by business size for policies directed towards SMEs, or by industry for policies that target specific sectors or export-led development.[17] Industry level indicators should be available for two-digit ISIC industries for all manufacturing sectors and for selected service sectors[18]. Indicators at the three or four digit ISIC level could be required if targeting is for specific fields, for instance applications of biotechnology or robotics.

Indicators on the educational performance of high school and university students need only be available at the regional level, but indicators for the educational attainment of employees should be available, at the minimum, for the manufacturing and service sectors and if possible at ISIC 2 digit levels within manufacturing and services. Similarly, innovation and R&D indicators should be provided for each two-digit industry.

3.2.3 Using 'big data' to construct indicators

Most STI indicators are constructed from administrative or survey data, but there is growing interest in using automated methods to exploit 'big data' sources, such as the internet or data collected by devices such as smartphones. These methods could be especially relevant for constructing indicators for innovation, given the lack of relevant administrative data and the high cost of innovation surveys. The main methodology is data mining by web-scraping bots that use textual analysis to identify innovation activities that are posted on the websites of businesses or public sector organizations such as municipalities or government agencies, or media reports and databases[19]. However, research to date finds that web-scraping methods substantially underestimate innovation activities.[20]

The use of data mining to identify innovation activities requires finding methods to solve three issues that reduce the reliability of web-scraping:

1. Self-selection caused by organizations only posting information that they want to make public. For instance, businesses may not report a process innovation in order to keep it secret from its competitors.
2. Different organizations report data in different ways and use different terms to describe innovation activities. Web-scraping methods need to be able to extract an activity or type of innovation from multiple descriptions. Machine learning is likely to be helpful for this purpose.
3. Poor representativeness, whereby some businesses are more visible than others. Small businesses could lack a website or only post a minimal amount of information.

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[16] http://www.oecd.org/innovation/inno/inno-stats.htm.

[17] Arundel et al, 2006.

[18] Table 91 (p.183) of the 4th edition of the Oslo Manual provides a list of recommended service sectors for inclusion in innovation surveys.

[19] See OECD/Eurostat 2018, p 58.

[20] Côté and Stanciauskas, 2018.

A report for the European Commission describes experiments with the use of big data to produce several innovation indicators, some of which can be verified against other data sources.[21] Examples include using web scraping to estimate the number of university spin-offs, start-ups, accelerators and incubators in the UK. Web-scraping only identified approximately half of known incubators and accelerators. The most useful application of big data was to produce statistics for which there were no other data sources, such as the number of businesses active in virtual reality technology.

The track record for using big data to create innovation indicators is so far poor, with analyses of internet and other big data sources unable to replicate the accuracy and breadth of innovation surveys. However, these are early days for this type of research – future experimentation with big data should result in better quality indicators.

3.2.4 Necessary government expertise

As discussed in the companion report on STI priorities, an important goal for policy is to improve the innovative capabilities of businesses in all sectors, which requires relevant indicators for all sectors, in addition to indicators for specific targeted sectors of interest.

Indicators need data collection and analysis. Some indicators can be collected from international administrative sources (ie. international patents and bibliometrics) and others from domestic administrative sources (capital expenditure and value-added), but many indicators need to be collected from surveys (R&D, innovation, knowledge-transfer, etc.). These surveys should be conducted by an experienced National Statistical Office (NSO), or by subject experts. The production of indicators also requires expertise.

A major requirement for policy is expertise in econometric evaluation of indicator data to identify the factors that hinder and support innovation activities, capabilities and outcomes and to track changes in productivity at the sector level. This requirement can be met either through an in-house econometric unit within government or by external national academics.

3.3 International Experience with STI Indicators

This section covers the state-of-the-art for STI indicators, including leading edge research and experimentation for developing new STI indicators. This section therefore summarizes what is possible. In practical terms, no country or region collects, on a regular basis, the majority of indicators described in this section.

Table 2 summarizes thirteen categories of STI indicators. The first four (human resources, R&D, bibliometrics and patents / design registration) cover science and technology. The next three categories (entrepreneurship, knowledge transfer, demand) cover activities that can result in innovation. The remaining six activities provide different measures of innovation (capital expenditures, trade, digitalization, innovation, environmental innovation, and public sector innovation).

Since the 1960s, the development of many STI indicators has been coordinated by NESTI (National Experts on Science and Technology Indicators) a working party of the OECD. NESTI members have included academics and statisticians from multiple National Statistical Organisations with expertise in measurement and economic analysis. NESTI is responsible for several OECD Manuals that provide guidelines for measuring science, technology and innovation. The first Frascati Manual of 1962 provided advice on the measurement of R&D, with the most recent edition of the Frascati Manual

[21] Nesta, 2018.

published in 2015. Other relevant Manuals include the 1992 Oslo Manual guidelines for measuring innovation (the most recent fourth edition is from 2018), the Patent Statistics Manual of 1994, the 1995 Canberra Manual for measuring human resources for science and technology, and the 2007 OECD/Eurostat Manual on Business Demography Statistics, which includes indicators for entrepreneurship. These OECD manuals cover five of the thirteen categories of STI indicators summarized in Table 2. Although not providing a Manual, the OECD provides advice on measurement for four of the eight remaining categories: bibliometrics (the OECD provides a compendium that can serve as a Manual), digitalization (for which the OECD has provided some guidance, but not a Manual), demand for innovation (the OECD provides a working paper on government procurement) and trade in innovative goods and services (the OECD provides a relevant database). The OECD does not provide the best available advice on measurement for knowledge transfer from universities and public research institutes to businesses, environmental innovation, and public sector innovation. The European Commission's Joint Research Council provides guidelines for measuring knowledge transfer, with an update in 2020, and MERIT in the Netherlands coordinated the production of a 2019 Manual for environmental innovation that closely follows the structure of the OECD Manuals. There is currently no manual for public sector innovation, but experimentation on measurement in this sector over the past decade has led to some coverage in the Oslo Manual and relevant research publications (see citations to Table 2).

The purpose of the OECD NESTI working party and the OECD Manuals is to provide definitions and measurement guidelines that can be used by all countries – thereby ensuring cross-country comparability of indicators. The Manuals are updated to take into consideration further research and experience. For instance, the Oslo Manual guidelines for measuring innovation have been revised three times since the first Oslo Manual of 1992 that focused on technological innovation in the manufacturing sectors of high-income countries. Since then, the Manual has been extended to cover services and non-technological innovations. The most recent edition also incorporated experience from the Bogota Manual on measuring innovation in middle-income countries. Due to the expertise, experience and research behind each OECD Manual and the other references listed in Table 2, indicator construction should follow their recommendations when relevant.

The cited references and data sources in Table 2 cover a range of possible indicators. Other than altering indicators for specific sectors or regions in order to address policy needs, there is rarely a need to invent new S&T indicators for eight of the categories in Table 2: human resources, R&D, bibliometrics, patents and industrial design, knowledge transfer, capital expenditures, trade and digitalization. The other categories of entrepreneurship, demand, environmental innovation, public sector innovation, and innovation itself are open to the development of new indicators for relevant activities, although many useful indicators have been identified for these categories.

The OECD also publishes data for a wide range of STI indicators for OECD member states and a few other countries (Argentina, China, Columbia, Russia, and Turkey). The OECD's MSTI (Main Science and Technology Indicators) database[22] includes data on four main classes of indicators: R&D (over 60 indicators), human resources, patents, and trade in high technology goods (pharmaceuticals, ICT (computers, electronics and optical), and aerospace). Additional patent data are available in the OECD patent statistics database.[23] Innovation statistics, derived from innovation surveys, are available in the OECD innovation compendium on a biennial basis from 2013 to 2019.[24]

[22] https://www.oecd.org/sti/msti.htm

[23] https://www.oecd-ilibrary.org/science-and-technology/data/oecd-patent-statistics_patent-data-en.

[24] http://www.oecd.org/innovation/inno/inno-stats.htm.

Table 2 Categories of STI indicators

Categories of STI indicators						
Category	**Manuals / references**	**Target**	**Data sources**	**Main uses**	**Advantages**	**Disadvantages**
1. Human resources	OECD Canberra Manual, 1995[1] OECD Mapping Careers & Mobility of Doctorate Holders, 2012[2]	Human resources for S&T	Education, Labour Force and R&D statistics (survey based); censuses	Domestic and international stocks and flows of technicians and personnel with tertiary education in science and engineering or working in S&T occupations	Low cost as obtained from existing surveys Annual update	Choice of educational fields and occupations of relevance to S&T will both under- and over-represent resources. Manual due for an update.
2. Creation of new knowledge (R&D, design thinking, co-creation)	OECD Frascati Manual, 2015,[3] OECD MSTI database	Businesses and governments	R&D surveys, innovation surveys	Identifying R&D expenditures and personnel, by sector; identifying use of design thinking and co-creation	Most useful inputs for creating new technology	High cost due to the need for surveys
3. Bibliometrics	OECD Compendium of Bibliometric Science Indicators, 2016[4]	S&T peer-reviewed publications (mostly in English)	Google scholar, Scopus (private)	Identifying leading research by technology field for businesses, universities, industry, etc. Identifying collaboration (joint patents) Science forecasting Trend analyses	Moderate cost Frequent updates	Distance from innovation Bias towards English Language journals
4. Patents & design registrations	OECD Patent Statistics Manuals (1994, 2009)[5]	Inventions New designs	National and international patent and design registration databases	Identifying invention activities by technology field for businesses, universities, industry, etc. Identifying new designs by sector Identifying collaboration (joint patents) Technology forecasting	Low cost Low lag for availability of approximately 6 months	Many inventions are not patented Patent applications reflect appropriation strategies; better coverage of products than processes

Categories of STI indicators						
Category	**Manuals / references**	**Target**	**Data sources**	**Main uses**	**Advantages**	**Disadvantages**
				Trend analyses		Value of specific patents highly variable
5. Entre-preneurship & venture capital	OECD/Eurostat Manual on Business Demography Statistics[6]	Businesses	National accounts, surveys of Venture Capital (VC) firms	Identifying fast-growing new businesses in innovative sectors	Low cost if using National Accounts, moderate costs for surveying VC firms	High churn and therefore need to track business exits Difficult to exclude new businesses with few innovative characteristics
6.Knowledge transfer	Metrics for Knowledge Transfer from Public Research Organisations in Europe, 2009[7]; Knowledge Transfer Metrics. Towards a European-wide set of harmonised indicators, 2020[8].	Knowledge Transfer Offices at universities and public research institutes	Specialized surveys	Measuring licensing, contracting and collaborative research that transfers new knowledge to businesses and start-ups	Moderate cost Source of data for linkages between universities (a key policy focus) and businesses.	Knowledge transfer that is not based on licensing can be under-reported. Transferred knowledge may not be commercialised (result in an innovation)
7. Demand for innovation	No Manual, but an OECD working paper on the role of procurement[9]	Procurement by public sector FDI demand	Specialized survey	Measuring procurement activities that require innovation Measuring role of FDI in demanding upgrades by domestic businesses	Procurement policies to support innovation	High cost, experimental
8. Capital expenditures	Chapter 4 of the Oslo Manual (2018)	Businesses	National accounts (CAPEX survey)	Capital expenditures on equipment etc. are a major source of innovation via diffusion	Low cost	Not all capital expenditures are for new-to-firm equipment

Categories of STI indicators						
Category	**Manuals / references**	**Target**	**Data sources**	**Main uses**	**Advantages**	**Disadvantages**
9. Digitalization	OECD Measuring the digital transformation, 2019[10]	Digital economic activity and innovation	Various listed above plus Venture Capital, open government, and OECD STAN data	Investment and innovation in ICT and related digital technologies	Low cost for many indicators derived from existing data Focus on digital, covers diffusion and creation New areas such as AI, big data	Rapid rate of change requires frequent updating of indicators
10. Trade in advanced products	OECD TiVA database	Imports, exports and trade balances	Trade data	Measure exports and imports of goods with a high innovation content.	Low cost	Innovation content of exports can be very low if value-added activity limited to assembling inputs
11. Innovation	OECD Oslo Manual, 2018[11]	Businesses	Specialized surveys	Measuring innovation inputs, activities, outputs and outcomes Identifying factors that hinder or prevent innovation	Only available representative data for innovation	High cost Limited ability to obtain interval level data
12. Environ-mental innovation	Maastricht Manual on Measuring Eco-Innovation for a Green Economy (Kemp et al, 2019)[12]	Businesses, governments, households	Various: patents, investment, sales, specialized surveys	Measuring environmental innovation inputs, activities, outputs and outcomes	Relevant to key social goals (reduce CO^2 emissions, clean water, etc.)	High cost Many indicators are experimental
13. Public sector innovation	No key manual, but covered in the Oslo Manual and by Arundel et al (2019)[13]	Public sector organisations	Specialized survey	Measuring innovation inputs, activities, outputs and outcomes Identifying factors that hinder or prevent innovation	Public sector has multiple opportunities for innovation	High cost Some indicators are experimental

1: OECD, Manual on the Measurement of Human Resources Devoted to S&T - Canberra Manual, 1995, https://www.oecd-ilibrary.org/science-and-technology/measurement-of-scientific-and-technological-activities_9789264065581-en

2. OECD, Mapping Careers and Mobility of Doctorate Holders: Draft Guidelines, Model Questionnaire and Indicators – Third Edition. https://www.oecd-ilibrary.org/search?value1=Mapping+Careers+%26+Mobility+of+Doctorate+Holders&option1=quicksearch&facetOptions=51&facetNames=pub_igoId_facet&operator51=AND&option51=pub_igoId_facet&value51=%27igo%2Foecd%27&publisherId=%2Fcontent%2Figo%2Foecd&searchType=quick

3: OECD Frascati Manual, 2015. http://www.oecd.org/sti/frascati-manual-2015-9789264239012-en.htm; OECD Main Science and Technology Indicators (MSTI) https://www.oecd.org/sti/msti.htm.

4: OECD Compendium of Bibliometric Science Indicators, 2016, http://www.oecd.org/sti/inno/Bibliometrics-Compendium.pdf. · The authors stress that this publication does not provide guidelines for data collection and indicator construction, but it can still serve this purpose. Other sources are Rehn et al http://kib.ki.se/sites/default/files/bibliometric_handbook_2014.pdf .

5. OECD Patent Statistics Manual, http://www.oecd.org/sti/inno/oecdpatentstatisticsmanual.htm., and OECD Patent database, https://www.oecd-ilibrary.org/science-and-technology/data/oecd-patent-statistics_patent-data-en.

6. Eurostat-OECD Manual on Business Demography Statistics, 2007, http://www.oecd.org/sdd/business-stats/39974460.pdf.

OECD, Entrepreneurship at a Glance, 2017, https://www.oecd-ilibrary.org/docserver/entrepreneur_aag-2017-en.pdf?expires=1596691477&id=id&accname=guest&checksum=E1935E4C132EA5DB93681D002F07F624.

7. Finne H, Arundel A, Balling G, Brisson P, Erselius J. *Metrics for Knowledge Transfer from Public Research Organisations in Europe*, Report from the European Commission's Expert Group on Knowledge Transfer Metrics, DG Research, European Commission, Brussels, 2009. *https://op.europa.eu/en/publication-detail/-/publication/d0dbd13d-6b28-4398-896b-0fe9cf0ed2cb.*

8. Campbell A et al. Knowledge Transfer Metrics - Towards a European-wide set of harmonised indicators, 2020. https://ec.europa.eu/jrc/en/publication/knowledge-transfer-metrics-towards-european-wide-set-harmonised-indicators.

9. Appelt and Galinda-Rueda, Measuring the link between public procurement and innovation, OECD 2016. https://www.oecd-ilibrary.org/docserver/5jlvc7sl1w7h-en.pdf?expires=1596701747&id=id&accname=guest&checksum=8512DAC8374539BFBB3962961EACAEC3.

10. OECD, Measuring the Digital Transformation, 2019. https://www.oecd-ilibrary.org/science-and-technology/measuring-the-digital-transformation_9789264311992-en. See also OECD, Entrepreneurship at a Glance, 2017, https://www.oecd-ilibrary.org/industry-and-services/entrepreneurship-at-a-glance_22266941.

11. OECD/Eurostat, Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition, http://www.oecd.org/science/oslo-manual-2018-9789264304604-en.htm.

12. Kemp et al, Maastricht Manual on Measuring Eco-Innovation for a Green Economy: https://www.inno4sd.net/uploads/originals/1/inno4sd-pub-mgd-02-2019-fnl-maastrich-manual-ecoinnovation-isbn.pdf.

13. Arundel et al, 2019. *Research Policy*, 48: 789-798, 2019, https://www.sciencedirect.com/science/article/pii/S0048733318302956.

The next sections briefly describe each of the categories of STI indicators and their policy relevance.

3.3.1 Human resources

An educated population is perhaps the single most important input to economic development through innovation. Human resource indicators measure the highest level of educational attainment, from high school to PhDs. Indicators can be provided for the highest level of educational attainment in specific fields, such as STEM subjects (science, technology, engineering and mathematics). Relevant data are obtained from household surveys, employer surveys, or the graduation records of tertiary institutes.

Tertiary education fields other than STEM can also be of high importance to innovation. Product innovation will benefit from personnel with expertise in marketing, graphic art, and industrial design. Almost all sectors benefit from tertiary education in management and logistics.

In addition to indicators by level of educational attainment, indicators can be provided by occupation, such as the number of individuals employed as researchers in both the public and private sectors. Priority targeting by sector requires data on the percentage of employees in a sector by their highest level of educational attainment, by field of education, and the percentage of employees with research positions or otherwise involved in innovation activities.

3.3.2 Creation of new knowledge

New knowledge can be created through R&D, design thinking, and co-creation activities. R&D is the most widely known indicator for knowledge creation, in part because it has been widely used in manufacturing for over a century. Design thinking is a process for improving the usability of goods and services and in many service sectors is considerably more important than R&D. Co-creation involves the joint creation of new goods and services between businesses or governments and the potential users of goods and services.

R&D indicators were among the first STI indicators to be created and are arguably the most important general indicator of high-level innovation capabilities in the business sector. Multiple types of R&D indicators can be constructed (see the OECD's MSTI database), but one of the most important indicators for sectoral targeting policies is business expenditures on R&D (BERD) as a share of value-added in the sector of interest. If value-added is not available, the indicator can be given as BERD as a share of total sales, but using value-added is considerably more useful because it is linked to the share of value added by the domestic economy, which is driven by innovation. Total sales are strongly affected by the cost of inputs to products, many of which could be imported.

R&D indicators for a priority sector need to be supplemented by R&D indicators in the higher education and government sectors for related fields of science. For instance, if pharmaceuticals is a priority sector, data are required on total BERD by pharmaceutical and allied businesses and R&D expenditures by universities and government research institutes for relevant science fields (organic chemistry, microbiology, biotechnology, immunology etc.).

R&D indicators are obtained from R&D surveys of businesses and relevant organizations in higher education and government.

Design thinking and co-creation, although in use for decades by businesses, have only recently been recognized. For example, the OECD's Oslo Manual did not include design thinking and co-creation until the 4^{th} edition of 2018. Information on both can be collected through innovation surveys. Design thinking is an interactive and iterative process for problem solving that focuses on identifying the problem and user needs.[25] It can be combined with R&D activities or co-creation or used by itself. Co-creation involves potential users in the development of goods and services. Co-creation has significant advantages in reducing errors and ensuring that a good or service is fit-for-purpose and usable. Governments increasingly combine co-creation and design thinking to develop public services.[26]

3.3.3 Bibliometrics

Bibliometrics measure peer-reviewed publications in science and many other fields. They can be used to track, over time, the academic output of universities and research institutes and domestic and international collaboration. Citations can be used to identify high-quality publications that are at the leading edge of research. Indicators for international collaboration are of value to measuring knowledge transfer that can increase domestic expertise. Bibliometrics can also be used to identify publication output in fields of relevance to priority sectors and to forecast future trends (as with patents). The disadvantage of bibliometrics is that they are heavily biased towards English-language journals.

Several privately owned databases of publications, such as Scopus, can be used to produce bibliometric indicators.

3.3.4 Patents and design registrations

Patent indicators can be used to track R&D outcomes in specific technology fields by universities, research institutes and businesses. They can also be used to identify technology fields that are attracting increasing public and private interest globally. However, patents have limited value in identifying innovation because many commercially valuable discoveries are not patented and a patented invention may never result in a commercial product.

Design registrations are much closer to identifying commercialised products, since they protect the shape or appearance of goods or services that are very likely to be commercialized. It is possible to link design registrations to businesses in priority sectors.

The Oslo Manual defines designs that make a significant contribution to utility or usability as innovations. A product's commercial success can be improved by combining good design with other innovative characteristics. The disadvantage of indicators for design registration is that businesses can register minor design changes (that do not meet the requirement for an innovation) for non-innovative products. Therefore, indicators constructed from data on design registrations will include some products that are not innovations.

WIPO maintains a global database for design registrations[27] and for patents via PCT[28] filing practices. Other useful patent databases are the USPTO (US Patent and Trademark Office, JPO (Japan Patent Office), EPO (European Patent Office) and SIPO (Chinese Patent Office). Patent applications via the PCT or the main patent offices are often of higher quality than patents that are only filed in other countries or jurisdictions.

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[25] https://mitsloan.mit.edu/ideas-made-to-matter/design-thinking-explained

[26] Alves, 2013.

[27] https://www.wipo.int/reference/en/designdb/.

[28] Patent Cooperation Treaty filings are used to file a patent application in more than one jurisdiction.

3.3.5 Entrepreneurship and venture capital

Entrepreneurship concerns the establishment of new businesses. The main interest in terms of STI indicators is new businesses (less than 5 years old) with product innovations or new business models. New businesses can be created by individuals, spun off from larger businesses, or spun off from universities or public research institutes. Indicators of relevance to innovative entrepreneurship include start-up formation by universities and businesses and innovative fast growing 'gazelles' (businesses that are less than 5 years old with an R&D intensity above 10% and sales growth of 20% or more per year). Data on the number and survival of start-ups (or spin-offs) from universities and research institutes can be obtained from surveys of KTOs that serve these organizations. Relevant indicators include the annual number of start-ups per 1,000 researchers or per million dollars of research expenditures. Gazelles can be identified from administrative data.

Venture capital (VC) supply and management training can be essential inputs for entrepreneurial new businesses. A common indicator is total venture capital investments as a share of national GDP, but this indicator includes substantial VC investment in businesses that are not necessarily innovative, such as new businesses in the retail sector, or total VC could be dominated by funding for relatively established businesses. The indicator can be limited to investments that are most relevant to the establishment, survival and growth of new businesses: seed, start-up, early development and expansion stage venture capital. If available, VC indicators should also be provided by industry in order to exclude industries of low interest. VC data are usually available from national associations of VC firms.

3.3.6 Knowledge transfer

Knowledge transfer concerns knowledge flows from the public research sector (universities and research institutes) to businesses or government organisations. This can occur via formal and informal methods. Formal methods are based on a contract for a specific service and include research agreements, consultancy, the licensing of intellectual property such as patents or plant breeder rights, and the establishment of spin-offs. Informal methods for transferring knowledge to businesses include publications, conference presentations, personal contacts, job exchanges, and hiring by businesses of university graduates or research staff.[29]

After R&D, innovation policy in many countries has focused on supporting and measuring formal knowledge transfer activities. There are several reasons for this focus: universities are under the direct control of governments, making policy intervention a simple matter; the important role of universities and research institutes in creating (universities) and disseminating (research institutes) new technology, and evidence that academics will not participate in knowledge transfer without rules or incentives to encourage it.[30]

Policy support has often focused on licensing patents. This is partly due to the availability of patent statistics and the ease with which relevant information can be obtained on knowledge transfer via licensing and contracts from surveys of knowledge transfer offices (KTOs) affiliated with research universities and research institutes. Since there are only a small number of KTOs in each country, the cost of such a survey is low. For example, the AUTM in the United States collects relevant data on IP licensing activities from approximately 150 research-intensive American universities that account for over 80% of all federally-funded research.[31] In the UK the annual HE-BCI surveys (conducted by HESA)

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[29] Arundel and Wunsch-Vincent, 2021.

[30] Geuna and Musico, 2009.

[31] https://autm.net/AUTM/media/SurveyReportsPDF/AUTM_FY2018_US_Licensing_Survey.pdf

collects data for almost all British universities on IP licensing, collaboration, consultancy, contract research and other methods on interacting with businesses.[32]

Four indicators for knowledge transfer are commonly collected: 1) the number of research agreements, 2) the number of licenses for IP, 3) the number of start-ups established, and 4) the amount of licence income earned. Three other indicators such as the number of invention disclosures, patent applications and patent grants are widely collected, but these are less useful because no knowledge transfer may occur and consequently they may not lead to commercialisation.[33]

The main drawback to this group of indicators is that they fail to capture knowledge transfer via informal methods. This is unfortunate because of the considerable evidence showing that informal methods are more widely used by businesses than formal methods in many middle and high-income countries.[34] Relevant information on informal methods can be collected through surveys of KTOs, academics, or businesses.

3.3.7 Demand for innovation

Innovation is influenced by the supply of commercially useful knowledge (R&D, availability of new technology) and demand that provides an economic incentive for investment in innovation.[35] Demand for innovative products can be divided into domestic government and consumer demand as well as foreign demand for national goods and services. Demand has both quality (buyer sophistication or lead markets) and quantity aspects (expenditures on innovative goods and services). Most policy instruments have focused on supply side factors for innovation, partly because of a lack of good indicators for innovation demand.

Policies to support demand for innovations, such as government procurement, tax incentives, and regulations and standards, are most likely to be implemented when a public good is involved,[36] such as for innovations to reduce pollution or address climate change. Government procurement can be used as a policy lever to create demand for innovation within businesses, for instance if the procurement criteria require innovation and if the contract is large enough (relative to the size of the market) to either spur innovation investment or reward innovators.[37] Governments can also implement regulations and standards that require innovation to be met[38], or by encouraging changes in domestic consumption, for example through product safety standards, carbon cap and trade rules, or instruments to improve the attractiveness of purchasing zero CO^2 emission vehicles.[39]

The main source of data on the role of demand in innovation is through innovation surveys. The European CIS includes several questions of relevance to demand, although none of them measure the importance of sophisticated demand:

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[32] See https://www.hesa.ac.uk/data-and-analysis/business-community. Data are available on an annual basis from fiscal years 1998/1999 to 2018/2019.

[33] Finne et al, 2009.

[34] Cohen et al, 2000; relevant country chapters in Arundel et al, 2021.

[35] Utterback and Abernathy, 1975.

[36] Edler and Georghiou, 2007.

[37] Lember et al, 2014.

[38] Hawkins et al, 1995.

[39] Kemp et al, 2019.

1. The firm's market: the survey asks the respondent to indicate which of several markets they are active in: local, national, and international.
2. The type of customer: governments, other businesses, or the general public.
3. Responsiveness to customers or to meet regulations as an innovation objective.
4. The importance of a lack of demand or uncertain demand for innovative goods and services as a barrier to innovation.

The 2009 European Innobarometer survey asked businesses if they had experience in responding to a government procurement contract and, if yes, if innovation played a role in a successful bid:

> "For a company to be successful in public procurement, do you consider that:
>
> 1. Low cost is more important than innovation for winning a public tender
> 2. Innovation is more important than low cost for winning a public tender
> 3. Cost and innovation have equal importance for winning public tenders"

3.3.8 Capital expenditures

A major form of process innovation for businesses is the purchase of capital equipment with characteristics or capabilities that the business did not previously possess. For example, a food products business could buy new automated packaging equipment that significantly reduces contamination by bacteria and other undesirable substances. The first CIS in Europe found that capital expenditures accounted for approximately half of all business spending on innovation.[40]

Data on capital equipment expenditures are available in national accounts under Gross Fixed Capital formation (GFCF), which covers the acquisition of fixed capital by businesses and institutions (due to purchases or production by the business or institution itself) minus disposals (sales, depreciation and losses) of fixed capital. The result gives the change in fixed assets during a given period.

The value of GFCF as a measure of investment in innovation depends on the assumption that new capital equipment contains technical improvements over existing stock. GFCF includes expenditures that are unlikely to be related to innovation, such as investment in livestock or dwellings and ownership transfer costs. The accuracy of GFCF as an innovation indicator can be improved by using the sub-category of investment in machinery and equipment. GFCF data are often available for three sectors: private businesses, public corporations, and the general government.

3.3.9 Digitization

Digitization is defined as "the encoding of information or procedures into binary bits that can be read and manipulated by computers".[41] The changes produced by digitisation and the effects on economic and social activity constitute "digital transformation" or *digitalisation*. The digitisation of many activities in both manufacturing and services is a dominant economic and technological trend of our era that can create new markets and enhance productivity. For this reason, digitization attracts policy interest and support. New developments include Industry 4.0, the Internet of Things, big data, cloud computing and AI.

Indicators for digitisation have been obtained from surveys of ICT use (for instance the share of the population that are internet users), while patent data are used to estimate future trends and identify

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[40] Evangelista et al, 1997.

[41] Ahmad and Ribarsky, 2018.

areas of national research strengths (OECD, digital, p 36). Digitization is increasing rapidly. Previous indicators, such as the percentage of the population that have access to the internet, have become obsolete, as they reach saturation levels. For instance, in high-income countries close to all potential users of the internet have access via a smart phone, home computer or other device, or work computer. Several indicators are necessary to identify how different sectors are positioned in terms of the adoption and use of digital technologies.

A study for the OECD measured the digitalization of specific sectors in 12 countries through five indicators: 1) ICT equipment and software investment as a share of total fixed investment, 2) purchases of ICT intermediate goods and services relative to output; 3) the number of robots per employee, 4) the number of ICT specialists as a share of total employment, and 5) engagement in e-commerce sales. The first indicator should also include an estimate of the value of ICT embodied in other types of capital equipment, such as complex machinery.[42] A second study proposed five indicators for measuring the economic contribution of digitalization to an economy: 1) total purchases of digital goods (ICT goods), 2) total purchases of digital services, 3) total value of e-commerce purchases (digitally ordered goods and services), 4) total value of services intermediated by digital platforms, and 5) the imputed value of free digital services to households and industries.[32]

3.3.10 Trade in product and service innovations

The value of trade data for innovative versus non-innovative goods and services lies in the positive impacts on terms of trade from innovative exports, which usually obtain higher prices due to a higher content of value-added. Imports of goods and service innovations are also of interest, especially when they are intermediate inputs to other economic outputs.

The innovative characteristics of traded goods and services is captured by Trade in Value Added (TiVA) indicators, although value-added can be produced without innovation activities. Indicators of gross exports, such as high tech net exports, should not be used as an innovation indicator because they can be vastly inflated from the inclusion of exports from simple assembly operations. The value-added of exports is the most relevant trade indicator for innovation. Gross imports of high tech goods or services are acceptable, but a better indicator is imports of high tech intermediate goods and services. This excludes final consumption products that do not create additional value in the economy.

The OECD Inter-Country Input-Output (ICIO) database[43] includes TiVA data for 36 two-digit industries (ISIC 4^{th} edition) for 64 countries including Viet Nam. A major disadvantage of the OECD ICIO data is that the most recent data are for 2015. The five-year lag reduces the value of this data for tracking current trends or the effects of recent policy changes on export outcomes.

3.3.11 Innovation

The policy interest in innovation activities and capabilities is substantial because innovation is required to turn S&T into product and process innovations and subsequently into economic and social outcomes. Policy can benefit from indicators for the propensity to innovate, innovation activities, the innovation capabilities of businesses, and innovation outcomes. Differences in innovation capabilities are likely to lead to differences in productivity improvements and competitiveness.

Innovation occurs on a continuum, ranging from the adoption of new technology “off the shelf” to a new product or process that required millions of dollars of in-house R&D to develop and implement.

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[42] Calvino et al, 2018

[43] http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

The 'innovative' continuum can be divided into four methods that businesses use to innovate. Each method also points to different types of innovation activities and capabilities. The methods include:

1. *Technology adoption*: businesses acquire innovative products and processes from sources external to the firm, with little or no further work required. An analysis of European CIS data found that the acquisition of new machinery and equipment is one of the most common innovation activities across businesses.[44] Similarly, businesses could acquire the ideas for organisational innovations from other businesses.
2. *Modifications or incremental changes*: Modifications can be made to both purchased products and processes and to in-house processes. These innovative activities are particularly common for process innovation. One study estimated that 15% of overall cost reductions are from incremental innovations.[45] Incremental change can depend on learning by doing and engineering expertise. Modifications can also be developed through imitation, including reverse engineering.
3. *Combining existing knowledge in new ways*: This can include some types of industrial design and engineering projects. This method of innovating builds on tacit knowledge, engineering skills and cumulative learning processes, where much of the necessary knowledge is located in the system, rather than limited to specific businesses.[46]
4. *Creation of new knowledge*: New knowledge can be created through R&D and design thinking. R&D requires creative work that is undertaken on a systematic basis to increase the stock of knowledge. R&D is usually required to change scientific discoveries into products or processes with commercial potential. When design thinking creates new knowledge, it is a subset of R&D.

Using innovation survey data, indicators can be constructed to identify the highest level of capability for each firm, with technology adoption requiring the lowest capability level and the creation of new knowledge the highest level. businesses can undertake technology adoption with very little creative activity or learning, but modifications, combining existing knowledge, and activities to create new knowledge require creative effort and learning on the part of the firm's employees and consequently develop the firm's in-house innovative capabilities.

Innovation activities of interest to policy include 1) knowledge-sourcing activities, such as obtaining knowledge of relevance to innovation from a range of sources outside the firm, 2) the use of collaboration to innovate; 3) incentives, drivers and objectives for innovation, 4) factors that can hinder innovation or act as a barrier to innovation, 5) strategies to support innovation, 6) competences of relevance to innovation (graphic arts, design, multimedia, marketing, software development, engineering and applied sciences), 7) the use of different appropriation methods (patents, industrial designs, secrecy, lead-time advantages, etc.), and 8) expenditures on different activities (equipment, training, design, software and databases, intellectual property, R&D, design engineering, co-creation).

Innovation outcomes can be measured as specific effects (reduction in pollution, increased safety, new products for new markets, etc.) or as the share of sales from product innovations.

To date, almost all innovation indicators have been obtained from surveys of businesses or other organisations such as public administration agencies. Experience with several experimental innovation surveys in the 1980s in Europe and the United States led to the first Olso Manual guidelines for measuring innovation, published in 1992, and the basis for the first European Community Innovation

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[44] Evangelista and Mastrostefano, 2006.

[45] Lhuillery and Bogers, 2006.

[46] Gottardi, 1996.

Survey (CIS) in 1993.[47] In addition to surveys, indicators for innovation outputs and outcomes could be collected through big data analysis such as web-scraping business websites, if issues with the accuracy of these methods are solved (see section 2.5).

The OECD's Oslo Manual[48] provides a comprehensive guide to the different types of data that can be collected through an innovation survey, while the OECD's innovation compendium provides a number of innovation indicators on a biennial basis from 2013 to 2019. Given wide differences in innovation capabilities and activities by business size and sector of activity, at a minimum innovation indicators should be provided for different size classes of businesses and for two-digit ISIC sectors.

3.3.12 Environmental or eco-innovations

An eco-innovation can be defined as a new or improved product or practice that generates lower environmental impacts, compared to the unit's previous products or practices, and that has been made available to potential users or brought into use by the unit.[49] The decision by a business or government to introduce an eco-innovation can be due to market-based pressures for cost-reduction, commercialisation prospects (demand from customers), and pressures from regulation, NGOs, clients or affiliated businesses. Eco-innovations can require the presence of internal capabilities, positive managerial expectations for potential gains compared to costs, and low expectations for risks.

There are three types of environmental innovation indicators:

- Environmental indicators (outcomes)
- Eco-innovation indicators (inputs and outputs)
- Socio-economic well-being indicators

Environmental indicators provide the baseline for measuring the outcomes (with suitable time lags) of eco-innovation activities. Examples include CO^2 emissions, NOx levels in urban air, and water quality indicators. These need to be absolute indicators (tonnes of CO^2 emitted) instead of relative indicators (CO^2 intensity of the economy) because the latter can decline without resulting in an improvement in air or water quality or a reduction in CO^2 emissions. Outcome Indicators can also include the effects of eco-innovations on the business itself, such as reductions within each business on CO^2 emissions. These are primarily due to process eco-innovations, but can also include the effects on the business from sales of product eco-innovations.

Eco-innovation indicators include inputs such as investments in environmental innovation (R&D by businesses, relevant invention disclosures at universities, etc.) and expenditures on the adoption of environmental technologies (including organizational innovations such as working from home or video-conferencing to replace travel). Relevant outputs include the different types of eco- innovations (products, production processes, organizational methods, etc.), the percentage of businesses or government agencies that have introduced a process eco-innovation, either developed in-house or adopted from external sources; the percentage that offered a product eco-innovation to potential users, and sales of product eco-innovations. Eco-innovations include the unintentional reduction of environmental impacts, such as the introduction of a new process to reduce expenditures on costly heavy metals such as cadmium, which has the effect of conserving and recycling heavy metals instead of releasing them into the environment.

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[47] Arundel and Smith, 2013.

[48] OECD/Eurostat, 2018.

[49] Kemp et al, 2019.

Indicators on socio-economic well-being play a valuable role in ensuring that shifts to a sustainable economy do not result in undesirable social side-effects. These include jobs created or eliminated, changes in competitiveness, as well as the turnover, revenues, profits and expenses of businesses.

Data for constructing eco-innovation indicators can be obtained from surveys of businesses, governments, households and knowledge transfer offices; annual corporate reports or websites (using web-scraping methods), patent databases, capital investment databases, and bibliometrics.

3.3.13 Public sector innovation

Improving the innovative capabilities of public sector organisations is an important policy goal in many countries, due to the significant share of GDP produced by the public sector, the need to improve the efficiency of processes in order to reduce costs, citizen demands for improved services, and social challenges from environmental, demographic, and quality-of-life issues.[50] Measurement of public sector innovation is in the experimental stage, with research using both innovation surveys adapted to the public sector and web-scraping methods. This section focuses on surveys due to limitations to date in web-scraping methods.

Many of the Oslo Manual guidelines for measuring innovation in the private sector can be applied to the public sector, with modifications to ensure that the results are useful for policy. This requires focusing survey questions on the methods used to innovate, innovation drivers (role of budgetary changes, ‘bottom up’ employee driven change versus political decisions, etc.), innovation obstacles (a culture of risk aversion, management or staff resistance, legal frameworks, etc.)[51] and specific outcomes such as an increase in the satisfaction of citizens with service innovations or cost reductions from process innovations.

Innovation methods can differ substantially from those used in the private sector. Public sector organizations tend to collaborate extensively with other government organisations and with non-governmental entities such as consultants and NGOs. They also readily copy successful processes and services used by other government organisations.[52] Public sector organizations rarely perform R&D, but they will use other creative methods such as design thinking and co-creation with staff for process innovations and with citizens or residents for service innovations.

Relevant indicators include the propensity to innovate for different types of innovations, cost reductions for process innovations, improvements to services, internal capabilities for innovation, and the use of knowledge sourcing methods and collaboration.

3.4 Use of indicators: Country Examples

Many indicators can be available without having any effect on the multiple and diverse STI policies that a government supports. To have an effect, the indicator needs to be evaluated and updated on a regular basis and the indicator must be provided to policy analysts in a timely manner (an indicator is of little use to policy if it refers to activities that occurred three years previously).

It is difficult to determine which of the many indicators collected by countries are actually used by government policy analysts because this needs to be studied for each policy. An example is given in section 4.3 below for knowledge transfer policies in Brazil, Korea and South Africa. Otherwise, we can assume that data collection and availability suggests that the indicator may have some influence on

[50] Arundel et al, 2019.

[51] Cinar et al, 2019.

[52] Arundel et al, 2015.

policy development. Confidence that the indicator could influence policy also increases if the indicator is included in national government reports.

3.4.1 Widely available indicators

The Global Innovation Index is a good source of indicators for non-OECD countries and includes indicators for 11 of the 13 categories identified in Table 2 (the exceptions are indicators for innovation and innovation demand). The GII coverage is generally good for science and technology inputs to innovation, but weak on other innovation inputs, activities, outputs and outcomes. The latter two types of indicators are only available for environmental and public sector innovation.

Table 3 provides an extraction of the best GII indicators for 11 categories. The GII includes many other indicators, but they are either of lower relevance to STI or variations on the indicators listed in Table 3, such as different versions of R&D indicators (these are still useful, but Table 3 highlights the most valuable STI indicators). Indicators marked in bold font in column 1 are both relevant to policy and of good quality. Other indicators are included because they are the best available, even though they are less useful (LU) or should be avoided entirely (A), for the following reasons:

- LU: The indicator for human resources of the percent of all tertiary students studying S&T should be replaced with the percent of the population between 18 and 29 studying S&T. Otherwise, good performance can be due to a very small share of students out of the student-age population.
- LU: The entrepreneurship indicator for VC is a count of deals, whereas a count of the value of deals is also required.
- LU: The entrepreneurship indicator of new businesses per thousand population includes all new businesses, many of which will not be very innovative (a new restaurant or consultancy) or will have zero employees (common in Australia).
- LU: The capital expenditure indicator includes all forms of capital expenditure (buildings, infrastructure, etc.), many of which will have no or only a slight innovation component. A better indicator is capital expenditure on new equipment and machinery.
- A: The knowledge transfer indicator for university-industry collaboration is from the WEF Expert Opinion Survey, which is likely to be biased towards university collaboration with large businesses. An indicator based on a representative sample of businesses or from KTO data would be considerably more accurate.
- A: The trade indicator is for high-tech exports minus re-exports, which includes the value of exports of assembled products. This is likely to explain the good performance of Viet Nam. A trade indicator needs to be based on the value-added of exports. It would also be useful to include separate indicators for the value-added of low- and mid- tech manufactured exports, which could contain a higher innovation content than high tech exports.
- A: The environmental indicator for GDP per unit of energy does not measure absolute declines in CO^2 emissions. A relative indicator such as this one could continually improve at the same time as CO^2 emissions continue to increase. Furthermore, the indicator should be based on the CO^2 equivalent emissions of the economy and not units of energy use.

What explains the large number of GII indicators that are not included in Table 3? First, many of the GII indicators for institutions, infrastructure, market sophistication and creative outputs can be important conditions for supporting STI or possible outcomes, but many of these indicators lack a close causal relationship with S&T activities and particularly with innovation. For instance, many of the creative output indicators measure both innovative and non-innovative activities, such as trademarks (applications are often for non-innovative goods and services), films or publishing. The conditions measured by the indicators for institutions and market sophistication are pursued for many policy reasons other than support for STI. Consequently these indicators are not very useful for benchmarking the effects of STI policies on innovation inputs, activities, outputs and outcomes.

Table 3 Selected STI Indicators in the Global Innovation Index

Type	Indicator	Korea	China	Australia	Brazil	Viet Nam
Human resources	S&T tertiary students, % all tertiary students	29.9	-	17.6	17.7	22.7
R&D	Gross Expenditures on R&D (GERD) as a % of GDP	4.6	2.1	1.9	1.3	0.5
R&D	Researchers FTE per million population	7,514	1,235	4,540	881	701
R&D	GERD performed by business, % GDP	3.6	1.7	1.0	-	0.4
R&D	Share GERD financed from abroad[1]	1.3	0.6	1.6	-	4.5
Bibliometrics	Scientific & technical articles/bn PPP$ GDP	20.4	11.9	26.9	9.7	5.6
Patents & industrial design	Patent families 2+ offices/bn PPP$ GDP[2]	14.4	1.0	1.0	0.1	0.0
Patents & industrial design	PCT patents by origin per bn PPP$ GDP[3]	8.0	2.1	1.4	0.2	0.0
Patents & industrial design	Industrial designs by origin/bn PPP$ GDP[4]	29.7	26.3	2.3	1.1	2.7
Entrepreneurship	Venture capital deals per bn PPP$ GDP[5]	0.0	0.1	0.1	0.0	0.0
Entrepreneurship	New businesses per thousand pop. 15-64[6]	2.6	-	15.5	0.1	-
Knowledge transfer	University-Industry research collaboration[7]	56.5	56.5	53.1	42.5	38.6
Demand	-	-	-	-	-	-
Capital Expenditures	Gross capital formation as a % of GDP[8]	31.2	44.2	24.3	16.1	27.5
Digitalization	ICT access index[9]	90.0	60.0	80.4	61.9	48.8
Trade	High-tech net exports, % of total trade[10]	26.4	27.9	1.7	4.5	32.9
Innovation	-	-	-	-	-	-
Environmental	GDP per unit energy use	6.3	6.6	8.5	10	6.7
Environmental	Environmental performance index[11]	62.3	50.7	74.1	60.7	47.0
Public sector	Government online service index[12]	97.9	76.1	97.2	92.4	73.6

1 Share of GERD funded by foreign finance as a percentage of total GERD.

2 Patents filed by residents of the country in two or more countries or jurisdictions.
3 Number of international patent applications filed by residents (first named applicant) of the country through the Patent Cooperation Treaty system.
4 Number of industrial designs filed by residents of the country at the relevant office within the country.
5 Number of VC deals within the country.
6 Includes all types of new businesses per thousand population between 15-64 years old.
7 Executive Opinion Survey for the question "In your country, do what extent do businesses and universities collaborate on R&D (1 = do not collaborate at all to 7 = collaborate extensively).
8 Gross capital formation includes the total value of fixed capital formation and changes in inventories and acquisitions, minus disposals.
9 Composite index for five ICT indicators: fixed telephone subscriptions per 100 inhabitants, 2) mobile phone subscriptions per 100 inhabitants, 3) international internet bandwith (bits/s) per internet user, 4) percentage of households with a computer, and 5) percentage of households with internet access. This is a summary of access to ICT by all sectors of an economy.
10 High tech exports minus re-exports. High tech includes aerospace, computers & office machines, electronics, telecommunications, pharmacy, scientific instruments, electrical machinery, chemistry, non-electrical machinery, and armaments. Some of these such as chemical and non-electrical machinery products are not 'high' technology. Re-export involves exporting an imported good without any transformation (re exporting a good "in the same state as previously imported"[53]. It does not exclude exports of imported parts that are assembled into new products.
11 Relative indicator from 0 to 100 that ranks countries on 24 indicators across 10 categories of environmental health and ecosystem vitality in 2018. The most recent 2020 version includes 32 indicators.[54]
12 Relative composite index (using the min-max method) on web based provision of public services by national governments within each country. The data are based on one or two researchers completing a questionnaire through assessing websites of relevant ministries.

3.4.2 Indicators in use for selected countries

A recent CSIRO report summarizes STI indicators in use to support policy by China, Malaysia, Japan, South Korea and Australia.[55] In all countries the most widely used indicators cover S&T and draw on R&D, human resources, intellectual property and bibliometric data, although Australia collects a broader range of indicators. This section provides additional details for China, South Korea and Australia, using both the CSIRO report and other sources.

China

The National Bureau of Statistics of China publishes an annual report on the innovation performance of the Chinese economy, summarized in an Innovation Index.[56] The index uses 21 indicators divided into four sub-categories: innovation environment index, innovation input index, innovation output index, and innovation effectiveness index. The index draws substantially on R&D, human resources, bibliometrics, and intellectual property (patents, trademarks etc.) data.

The innovation output index uses one indicator for human resources, two for patents, one for trademarks, and one for the total sales from contracted projects in the national technology market. None of these five indicators are innovation outputs, with all measuring inputs to innovation. The innovation effectiveness index contains a few interesting attempts to measure innovation outcomes. Two of these indicators are worth noting: the proportion of sales revenue for businesses from new products (not all new products are innovations, but many of them will be) and the generalized contribution of scientific and technological progress to economic growth. It is not clear how the latter indicator is constructed, but it could partially calculate total factor productivity. The remaining three indicators in this group are problematic and could be improved: the share of high-tech products in goods exports (this should be replaced by value-added), energy consumption per unit of GDP (this can be considered as an indicator of technical progress, but it is a highly misleading indicator of environmental benefits), and per employee business income (an approximation of labour

[53] https://unstats.un.org/unsd/tradekb/Knowledgebase/Reexports-and-Reimports.

[54] https://epi.yale.edu/.

[55] CSIRO, Measuring Innovation. The report also covers Singapore and Thailand, but very few details are provided for these two countries on indicator use.

[56] http://www.stats.gov.cn/english/PressRelease/201910/t20191025_1705429.html

productivity). No explanation is given for why value-added data are not used to calculate the trade and labour productivity indicators.

Some value-added data are available for China, with the Asia Policy Institute using the innovative industry share in industrial value-added as a primary indicator for evaluating economic conditions in China. This indicator has increased for 11 consecutive quarters and recently reached 33.2%, indicating that innovative industries play a growing role in China's manufacturing sector.[57] This is a measure of the structural adjustment in China from less or non-innovative industries to more innovative industries. The Asia Policy Institute also publishes estimates of value-added growth rates in specific industries and China's trade competitiveness in innovative products.

Republic of Korea

KISTEP, an organisation responsible for science and technology foresight and planning, collects and publishes a substantial number of indicators for R&D[58], as well as indicators for human resources, intellectual property, and bibliometrics. The Republic of Korea also runs an innovation survey, with relevant innovation indicators published by the OECD in tabular format. These include the types of innovation outputs (product, process, marketing, etc.), use of collaboration and type of collaboration partner (suppliers, clients, higher education/government) and the share of sales from new-to -market products. Most innovation indicators are also disaggregated by business size, R&D status, and industry (manufacturing and service sector).

Australia

In addition to a wide range of indicators for human resources, R&D, intellectual property and bibliometrics, Australia has collected or experimented with other indicators for early stage entrepreneurship, fast-growing businesses, procurement, public sector innovation (e-government), knowledge transfer, and innovation profiles, using the innovation module within the Business Characteristics Survey. Six profiles are identified for the innovation activities and outcomes of businesses within a one year observation period: 1) a product or process innovation that was new to the world, 2) a product innovation that was only new to Australia, 3) modified products or processes available on international markets, 4) modified products or processes available in Australia, 5) only adopted existing products or processes without additional development, and 6) only had abandoned or ongoing innovation activities. In all of four business size categories, the most common profile was domestic modifiers (#4). Very few businesses were new-to-world product innovators, with Australia ranking 23rd out of 31 OECD countries in 2015. This low performance can partly be attributed to the use of a one-year reference period versus three years in most other OECD countries.

3.4.3 Knowledge transfer policies and indicators

This section gives examples of the collection of indicators for knowledge transfer from universities and research institutions, an important area for innovation policy. This involves three partners: academics and researchers that produce the knowledge, knowledge transfer offices (KTOs) that act as intermediaries, and businesses that can potentially use the knowledge to develop commercially viable products or processes. Governments can directly influence the knowledge transfer activities of universities and publicly-funded research institutions through a variety of policy and practices. Ideally, data on the perspectives and activities of each of the three partners should be collected, but in practice it is cheapest and easiest to collect data from surveys of KTOs, since there are usually no more than one KTO per university or research institute and all relevant questions can fit into a four to six page

[57] https://chinadashboard.asiasociety.org/winter-2019/page/innovation.

[58] https://www.kistep.re.kr/en/c3/sub3.jsp?.

questionnaire. Comparative data from a WIPO study[59] of the types of knowledge transfer indicators that are collected in several countries provide an interesting example of the level of information obtained to inform innovation policy.

The data, referring to 2015 to 2017 depending on the country, are for two high-income (Korea and the UK) and three middle-income countries (Brazil, China, and South Africa). Results on the types of indicators collected are available from national experts. The indicators are divided into three groups: main indicators that are commonly available from surveys of KTOs (data on patents can alternatively be extracted from patent data), supplementary indicators that are useful for policy, and indicators for the types of practices that are in place at the level of individual universities and research institutions. Table 4 provides results for the types of data that were available in each country.

Table 4 Knowledge transfer data collected in five countries, 2017

	China	Brazil	South Africa	UK	Korea
Main indicators					
Number of research agreements with businesses		✓		✓	
Number of invention disclosures			✓	✓	✓
Number of patent applications	✓	✓	✓	✓	✓
Number of patent grants	✓	✓	✓	✓	✓
Number of licenses with businesses		✓	✓	✓	✓
Amount of license income earned		✓	✓	✓	✓
Number of start-ups using University IP			✓	✓	✓
Supplementary indicators					
Number of license agreements based on a patent		✓	✓		✓
Number of license agreements by business size (employees)			✓	✓	✓
Number or percentage of licenses given out at no cost					✓
Number or percentage of exclusive licenses		✓	✓		✓
Number or percentage of licenses yielding revenue			✓	✓	✓
Amount of research funding provided by businesses			✓	✓	✓
Policies / practices at the institutional level					
Incentives for academics to disclose inventions	✓			✓	✓
Promotion of KT opportunities to the business sector	✓				
Written rules or guidelines for KT	✓		✓		✓
Rules over a delay in publication to permit IP licensing			✓		
Academics can take leave to work at a business or start-up	✓			✓	
Goals of knowledge transfer offices	✓		✓	✓	✓
Size of KT budget			✓		✓
Expenditures for patent applications		✓	✓	✓	

1: Source: Arundel A, 2021. Data for supplementary indicators is from unpublished data collected for a WIPO study.

Knowledge transfer from universities and research institutes to businesses can occur through research agreements, such as when a business contracts out research to a university, or via the licensing of new knowledge produced by a university without the prior involvement of a firm. Knowledge with potential

[59] The results are presented in Arundel et al, 2021.

commercial value are identified through invention disclosures. Both knowledge produced through research agreements and independently can be protected through different forms of intellectual property, with patents being the most common. Patents and other forms of IP can be licensed to businesses, providing license revenue to the university or research institute, or assigned to a start-up (or spin-off) business that can further develop the licensed knowledge into a product or process. The main indicators in Table 4 cover the major steps in these processes for knowledge transfer. Although non-patent forms of IP are not included, license revenue includes other forms such as IP protected by copyright, trade secrecy, plant breeder rights, etc.

The supplementary indicators are very valuable for policy goals such as supporting the capabilities of SMEs (license agreements by business size), the role of exclusivity in patenting (percentage of exclusive licenses), and the efficiency of licensing (percentage of licenses for patents, percentage of licenses yielding revenue). Data on policies reflect a large number of academic studies finding that knowledge transfer increases when academics are given incentives (usually a percentage of license revenue) and the right to work at a business or start-up that licenses the IP.[60] Other policies support the efforts of KTOs through practices to promote knowledge, established guidelines for goals and licensing practices, and adequate funding. Delays in publication can be required to support patent licensing.

Other than China, most countries collected data on 6 or 7 of the main indicators. Coverage was weaker for supplementary data. Data on institutional policies and practices vary considerably among the countries. Both Brazil and South Africa lacked data on incentives for academics to disclose inventions, and only the UK collected data on practices permitting academics to work for start-ups.

The country case studies found that many countries experienced a need to revise knowledge transfer policies in the face of both changing economic circumstances and policy failure. These changes would have benefited from a variety of relevant indicators, but most countries relied on patent data. This could have been due to a reluctance to change conceptions over what drives good outcomes from knowledge transfer and the importance in all countries of non-patent forms of knowledge transfer such as consultancy and contract research agreements, for which data were only available in Brazil and the UK.

In addition, there was a common pattern in several countries to develop policies to support only one of the partners in knowledge transfer (universities or research institutes), without sufficient actions to ensure that the other major partner, businesses, had the necessary capabilities to understand and apply the knowledge. As a result, policies to increase the output of patented inventions in Brazil, the Republic of Korea, China, and South Africa were not matched by an equivalent increase in patent licensing. Over time, the mix of policies and practices were changed to address inadequacies in existing policies (China, Brazil, South Africa, and the United Kingdom) or changing circumstances (Republic of Korea).

The results in Table 4 suggest that China was developing policy without sufficient data on the different parts of the knowledge transfer system, since it only obtained data on patent applications and grants (available from administrative data) and data on practices, although the latter was based on the assumption that all universities and research institutes followed legal requirements, although there could be considerable delays in implementation. However, China was able to address a lack of indicators through targeted academic research, combined with a few one-off surveys.[61] Studies identified immature technology markets for leading technologies and low levels of research capabilities among state-owned enterprises and Chinese businesses. One consequence was that more than half of all university patent licenses in China were granted to foreign investors. The limited R&D

[60] Geuna and Musico, 2019; Belenzon and Schankerman, 2009.

[61] See Chen et al, 2021.

capacity of Chinese domestic enterprises was a significant barrier for knowledge transfer to domestic businesses. Many enterprises in China were (and continue to be) at the middle or low end of global value chains, do not perform R&D, and consequently lack the ability to create and absorb the research discoveries of universities and public research institutes. In addition, academic research found that universities were only moderately oriented toward the needs of the market. Many university professors did not license their technology because they did not have the time and necessary experience for negotiations and marketing.

The basic data available on patenting and alternative data sources supported several changes to the 1996 Law on Promoting the Transformation of Scientific and Technological Achievements (PTSTA). The 2015 amendments removed legal barriers to knowledge transfer and provided incentives for universities and public research institutes to engage more actively in knowledge transfer activities. China's universities and public research institutes have taken up to seven actions to facilitate knowledge transfer: Increasing rewards and compensation for inventors and knowledge transfer contributors, establishing KTOs, marketing of scientific and technological outcomes, new initiatives to permit and encourage students to start their own businesses, and supporting knowledge transfer via university–industry collaboration, including the establishment of joint research institutes. Of significant importance, China also implemented an additional set of policies to improve the innovation capabilities of businesses.

Of note, all five countries (with recent exceptions for the UK) have mostly relied on metrics for knowledge transfer via IP. This creates two substantial issues. First, measurement implies that the measured activity is of high value, while unmeasured activities are of low value. Consequently, the act of measuring IP sends a strong signal to university managers (and policymakers) that more university IP is desirable, while other activities to transfer knowledge, such as consulting, contract research, exchange programs and informal contacts are viewed as unimportant. This is contradicted by research from both the United Kingdom and China showing that methods of knowledge transfer that do not use IP are considerably more important than IP-mediated channels, as proxied by the amount of income earned by public research organizations from IP versus other knowledge transfer methods[62].

KTO officers are often unaware of other knowledge transfer methods. Consequently metrics for other methods need to be collected from academics and businesses through surveys. Although such surveys are expensive, they only need to be conducted every three to five years.

[62] For example, in 2015–16 all universities in the United Kingdom combined earned £4.2 billion from all knowledge transfer activities, of which only £176 million (4.2 percent) was due to the licensing of IP (HEFCE, 2017).

4 PART 2: Recommended indicators and targets for Viet Nam

This section provides a list of recommended STI indicators to be collected in Viet Nam as part of measuring progress towards the goals for the 2020 – 2030 STI policy.[63] The indicators are relevant to many of the strategies and goals listed on pages 43 to 47 of the companion report on STI Priorities. These include indicators for:

- The start-up ecosystem
- The share of enterprises with innovation activities
- Foreign investment in R&D and innovation
- Technology acquisition from international sources
- Linkages between businesses and research institutes / universities
- S&T based enterprises
- Capabilities in priority technologies
- Capabilities of the public research and training infrastructure
- Capabilities of public research to respond to market demand
- Capabilities of the organizations producing goods and services (businesses, governments, etc.)
- Management of S&T and innovation
- Digital transformation
- Network of intermediary and knowledge transfer organisations
- Restructuring of service industries
- Adoption of high technology in manufacturing and other sectors

Of note, the indicators described below are relevant to many of the policy goals listed on pages 43 to 47 of the STI priority report, but the specific policies are not mentioned here. In addition, some specific policy goals are not covered, such as 'strengthen the protection and enforcement of IP' and 'expand and improve the system of standards and regulations' because these are part of the regulatory system and not an STI input, activity, output or outcome.

4.1 Framework for Indicator Collection

In this section the focus changes from categories of STI indicators (covered in Part 1) to the National Innovation System (NIS), which determines how different organisations interact to produce innovations. All categories of STI indicators are included, but they are discussed in reference to their role in an innovation system, which influences the ability for government policy to affect inputs, activities, outputs and outcomes.

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[63] Unfortunately, the author did not receive a list of indicators that are already available in Viet Nam, although one was requested at the 3 September 2020 meeting. Some indicators for Viet Nam are available from the Global Innovation Index (GII), but as noted above in section 2.4.1 these indicators are not sufficient and quality could be an issue for some of them.[63] For instance, the World Bank report on Viet Nam notes that the R&D data only cover 15% of the business sector. An innovation survey has also been conducted in Viet Nam, but it is not known if this survey is conducted on a regular basis.

Although there are multiple models of an NIS that includes framework conditions, institutions, government, the public research sector, businesses and non-profits, a much simpler model is all that is required for recommending indicators. This model essentially consists of two sectors.

The first is the public research and tertiary education sector, consisting of public and privately funded universities and public (government) and privately funded research institutes. These organisations provide research services, educate citizens and residents up to the post-doctorate level, and produce basic and applied research. Since this sector is dependent for a sizeable share of funding for education and research from the government, policy has a large and immediate effect on the behaviour and outcomes of this sector.

The second sector consists of private businesses, households, state-owned enterprises (SOEs), other government agencies (health, etc.) and non-profits. All of these create the goods and services that form the economy and draw on the education and research produced by the first sector, but for practical reasons the focus is usually on private businesses and SOEs, which jointly form the business sector. Policy can directly influence the activities of government agencies and SOEs, but will have varying influence on the activities of private businesses, non-profits and households.

A simple model assumes that the public research and education sector supplies new knowledge to the second sector, with the second sector providing demand. This simple model is a powerful guide to indicator selection. However, knowledge and skills are created and exchanged between these two sectors and within each sector, as when businesses exchange knowledge within alliances, or when spillovers occur between different organizations. Both of these sectors will also interact and exchange knowledge and skills with organizations located abroad – outside the National Innovation System. International connections are vitally important for building STI capabilities in all countries, since no single country produces all of the world's knowledge and technology.

STI indicators need to capture inputs, activities, outputs and outcomes within each sector, between the two sectors, and with organisations abroad. This creates three areas for STI indicators: **public research and training sector**, **business sector**, and **knowledge exchange**, both within Viet Nam and internationally. Of crucial importance, indicators are required for both **quantity** and **quality**. For instance, indicators of research outcomes must cover not only the number of publications, but the quality of publications, or the indicator must cover both aspects together, such as the number of publications in journals indexed by the Science Citation Index (SCI), or the number of publications in top-ranked peer-reviewed journals (for instance with a Scimago Q1 rank).

The production of STI indicators requires the following types of data or surveys:

1. R&D survey of businesses and public research organisations
2. Data for student graduation rates, plus supplementary data on post-graduation employment. This may be available from administrative records kept by universities.
3. Surveys of the knowledge transfer activities of public research organisations. These can usually be addressed to the knowledge transfer office (KTO) affiliated to each university or research institute.
4. Innovation survey of businesses, SOEs and possibly public sector organizations.
5. Labour force survey.

4.1.1 Targets and priority sectors

The collection of indicators over time can be used to assess progress towards pre-defined targets. There are two challenges with setting targets: 1) they must be achievable and 2) they can create perverse incentives that result in undesirable outcomes. Achievability depends on initial conditions and effective policies. The danger of perverse incentives needs to be identified where relevant and targets altered. Table 5 provides several examples of perverse incentives and their solutions. The solutions include a change in the targeted outcomes and a quality requirement for targets.

Setting an absolute target (number of new graduates, number of publications, etc.) for specific indicators requires data on baseline conditions in the most recent year available and information on the types of support policies and funding to achieve the target. A percentage change in a target can be estimated without baseline data, although this is helpful, but requires data on policy and funding.

Table 5 **Examples of perverse incentives and their solutions**

Target	Perverse outcome	Solution
1. Increase number of ***publications*** by universities and research institutes, both absolute numbers and number per 1000 research staff.	Rapid increase in number of low quality publications, including publications in journals that do not meet peer review standards.	***Quality requirement***: Only target publications in Scimago Q1 or Q2 journals or in journals included in the Science Citation Index.
2. Increase number of **patent applications** by universities and research institutes, both absolute numbers and number per 1000 research staff.	Rapid increase in patent applications and possibly grants in low cost jurisdictions with poor quality patent review processes. The resulting patents are of poor quality and few are licensed.	***Quality requirement***: Only target international patent applications and grants at patent offices with high quality review processes, such as the USPTO, JPO and EPO. ***Quality requirement***: Invest in a high quality patent review process for domestic patents in Viet Nam. ***Outcome requirement***: Change target focus from intermediate outputs such as patents to measures of knowledge transfer and commercialisation, for instance the share of patents that are licensed.
3. Increase national **R&D intensity**, for instance by 0.1 percentage points per year.	Increase in government funding of R&D by universities and research institutions is not matched by an increase in R&D performed by the business sector; increase in R&D does not lead to an increase in commercially viable outcomes.	***Quality requirement***: For applied R&D, require universities and public research institutes to have a business partner, with businesses actively involved in R&D projects; for basic and applied R&D, implement peer-review of research proposals. ***Outcome requirement***: Set a separate target for R&D expenditures in the business sector, such as a target for the fraction of R&D expenditures performed by businesses.

For example, a target for the number of new tertiary graduates in STEM subjects requires baseline data on graduation numbers, demographics (the size of future age cohorts), and the number of STEM places available and information on policies to increase the number of STEM places in tertiary institutions, overcome obstacles to students studying STEM subjects, and incentives, such as predicted employment demand in the government and business sectors, subsidies to study STEM subjects, etc. Predicting demand also requires information on government policies to support businesses to improve their innovation capabilities.

When no data are available, it is sometimes possible to set an approximate target based on experience in other countries. Due to a lack of baseline and other data, the tables in this section that provide lists of relevant indicators usually only describe the type of target and the rationale for the target. In some cases, a target is estimated based on experience in other countries, but these targets are only provided to provoke discussion. They should not be used without gathering the relevant baseline and policy data.

As discussed in the STI priority report, Viet Nam has priority areas for specific technologies or sectors. Almost all types of indicators can be disaggregated to collect data for priority sectors or research fields, but this requires collecting the necessary data at a granular level, usually by sector. Collecting data for the business sector on the use of and research into generic technologies that span multiple sectors, such as biotechnology or artificial intelligence (AI), requires customized surveys (technology use surveys) that focus on specific fields of science. Statistics Canada has designed and implemented specialized surveys on specific technologies such as biotechnology and the adoption of advanced manufacturing technology. These were sent to a sample of businesses in sectors where the use of these technologies was possible. For instance, the survey of biotechnology was sent to businesses active in pharmaceuticals, chemicals, agriculture, and industrial processes that use fermentation. The most recent Survey of Innovation and Business Strategy (SIBS) includes a module of questions on the use of advanced and emerging technologies in a general innovation survey sent to a sample of all businesses.[64]

4.2 Recommended Indicators for the Public Research and Training Sector

The main goals for these indicators are to measure 1) educational outputs such as graduates and lifelong learning and 2) research activities. Quality is of very high importance to avoid government expenditures with few or poor outcomes. Table 6 provides key indicators. All indicators should be provided on an annual basis.

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[64] See question 41 of the SIBS questionnaire for 2019/2020, which asks about the use of the following emerging technologies: nanotechnology, biotechnology, geomatics, AI, virtual reality, internet of things, blockchain and additive manufacturing.
https://www23.statcan.gc.ca/imdb/p3Instr.pl?Function=getInstrumentList&Item_Id=1261134&UL=1V&.

Table 6 **Recommended Indicators for the Public Research and Training Sector (all indicators are per year)**

Recommended Indicators for the Public Research and Training Sector (all indicators are per year)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale**
Human resources[4]	Number of new graduates in relevant non-science subjects (marketing, management, economics, urban planning, administration, graphic design, industrial design, etc. at the bachelors, masters, and PhD levels.	Skills needed for some types of innovation (organizational, business models, services) and for the successful commercialisation or internal use of all types of innovations.	Absolute % increase per year % of age cohorts with tertiary education	Essential skills for innovation. Target setting requires information on past trends and demographic estimates of age cohorts for the next ten years.
"	Number of new graduates in science, technology, engineering and maths (STEM) at the bachelors, masters, and PhD levels.	Skills needed for all types of innovation, but particularly important for goods and production process innovations in manufacturing and ICT innovations.	Absolute % increase per year % of age cohorts with tertiary education	Essential skills for innovation. Target setting requires information on past trends and demographic estimates of age cohorts for the next ten years.
"	Number of new graduates with a diploma or higher level skills *for how* to innovate	How to innovate is not an obvious activity, but it can be learned. Multiple disciplines are involved, such as technology and knowledge management, design thinking, problem solving, co-creation, and entrepreneurship. These skills are valuable for all sectors of the economy, including government.	Absolute % increase per year until an optimal level is reached (possibly 1 per 100 working age employees).	Foundational skills for successful and efficient innovation. Without these, the quality and commercial viability of goods and service innovations will suffer.
"	Number of higher education programs per region that offer diploma programs for how to innovate.	As these skills sets are often ignored (with the emphasis on STEM skills) it may be necessary to collect initial data on the availability of teaching programs for these skills.	Absolute % increase per year per 1000 students enrolled in relevant social and STEM sciences.	All regions should have at least one high quality program for these skills with a minimum of 10 experienced faculty including practitioners for each skill group.

Recommended Indicators for the Public Research and Training Sector (all indicators are per year)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale**
"	Number /percent of adults (after highest level of education) enrolled in up-skilling diploma programs (Continuing education). These programs can be offered by technical colleges, private institutions, universities, etc.[5]	Continual improvement of skills of older cohorts is necessary to improve the innovative capabilities of businesses.	Absolute % increase per year in working age population over 25 % of working age population that have taken courses to improve skills	Target depends on current skill levels. A minimum level of the number hours of class time is required.
R&D[1]	Total expenditures on R&D in STEM and relevant social sciences	Foundation of all basic and applied research	60% of current rate of growth in GDP per year for first five years.	Rate of growth is expected to gradually exceed the GDP growth rate, but possible inefficiencies in R&D expenditures as identified in the World Bank report should first be addressed to free up funding.
"	Expenditures and share of R&D in public research sector funded by 1) Vietnamese government, 2) domestic businesses (excluding foreign-owned subsidiaries), and 3) foreign subsidiaries and foreign government sources (EU framework funds, etc.)	Funding by businesses and foreign sources are indicative of the quality of research conducted by the Vietnamese public research sector.	At end of 10 years domestic funding from businesses should equal 5% - 10%, foreign funding 5%.	This is ambitious – in high-income countries total funding from these sources rarely exceeds 20% over the entire public research sector. Funding by businesses can be subsidized by the government.
"	Percent research grant funding decided on the basis of a competitive peer-reviewed process with a minimum of 3 reviewers.	Almost all funding (80% by value) should be decided competitively. The exceptions are small seed funding, funding for specific research by known experts, such as a research team within a government research institute. Peer reviewers must not be close colleagues to prevent gaming the process.	The 80% should be reached within 5 years.	Improves efficiency of funding.

Recommended Indicators for the Public Research and Training Sector (all indicators are per year)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale**
"	Percent peer-reviewed research funding over a defined amount (100,000 USD?) that includes at least one external reviewer located outside Viet Nam.	Protection against gaming the peer review process and ensures high-level expertise in areas where Viet Nam may be building capabilities. A minimum project value is needed to prevent excessive translation costs for bids.	100% of funding over a defined amount should be reached within 10 years.	Improves efficiency of funding.
Bibliometrics[4]	Number of publications in the SCI or social sciences citation index (SSCI).	Measure of high-quality research output. Provided by research disciplines and published for each university / research institute.	Depends on initial baseline, but could increase by 5% per year if sufficient policy incentives.	Improve quality of research and the ability to draw upon research outside Viet Nam.
"	Average number of publications in the SCI or social sciences citation index per FTE researcher equivalent in STEM and relevant social sciences. Provide separately for universities and research institutes.	Efficiency of high-quality research output. Should be averaged over research disciplines and published for each university / research institute.	Universities: 1 per FTE researcher, research institutes: 0.5 per FTE researcher.	Improve quality of research and the ability to draw upon research outside Viet Nam.
"	Average number of publications in Scimago Q1 ranked journals.	Incentive to publish in the for highest quality journals. Should be averaged over research disciplines and published for each university / research institute.	Universities: 0.5 per FTE researcher, research institutes: 0.25 per FTE researcher.	Improve quality of research and the ability to draw upon research outside Viet Nam.
"	Average number of citations per FTE researcher equivalent in STEM and relevant social sciences.	Measure of impact of research output. Can use citations to academic publications only or include citations to other output such as reports (ie. Google scholar).	Depends on initial baseline	Improve quality of research and diffusion of results.
IP[4]	Number of patents granted via PCT or at the EPO, USPTO, JPO, or SIPO.	Foreign patents are a good measure of patent quality.	Depends on initial baseline, which is currently close to zero. Only a small	Severe danger of gaming if patent applications used; also depends on funding mechanism for patent costs.

Recommended Indicators for the Public Research and Training Sector (all indicators are per year)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale**
			increase per year is plausible.	
"	Number of other forms of IP, particularly industrial design registrations and plant breeder rights.	These two forms of IP are close to market, unlike patents.	Depends on initial baseline.	
"	Number of patents granted via PCT or at the EPO, USPTO, JPO, or SIPO per 1,000 researchers.	Output measure of public research, should be provided for each university / research institute.	Depends on initial baseline, currently near zero.	

Notes for sources of indicators

1: R&D survey

2: business innovation survey

3: KTO survey

4. Administrative data (patents, trade, etc.)

5. Labour Force Survey.

4.3 Recommended Indicators for the Goods and Services Producing Sectors (SOEs, Businesses, etc.)

The main goals for these indicators are to measure 1) investments in innovation, 2) innovation capabilities within SOEs, businesses, governments, etc., 3) innovation outputs, and 4) up-skilling of employees. Table 7 provides a summary of recommended indicators. Indicators can be provided separately for businesses and SOEs combined and for the public sector.

Data on innovation capabilities and outputs require an innovation survey, although very basic data on innovation-active businesses (those with at least one innovation within a defined time period) can be obtained from the use of 'big data', such as web-scraping business websites. As noted in Part 1 (section 2.2.3), web-scraping will miss innovations that are not reported on websites and therefore tend to considerably underestimate innovation activity.

Data from innovation surveys can be used to construct *profiles* of businesses, SOEs and public sector organizations based on their innovation capabilities, ranked from highest to lowest level of capability. For example, one study used the European CIS to construct the following five profiles for businesses[65], although other methods of differentiating between business innovation capabilities are possible:[66]

1. *Strategic innovators:* Innovation is a core competitive strategy. These businesses perform R&D on a continuous basis to develop novel product or process innovations.
2. *Intermittent innovators:* These businesses perform R&D and develop innovations in-house when necessary or favorable, but innovation is not a core strategic activity. For some, their R&D efforts focus on adapting new technology developed by other businesses to their own needs.
3. *Modifiers:* These businesses modify their existing products or processes through non-R&D based activities. Many businesses in this group are essentially process innovators that innovate through production engineering.
4. *Adopters:* These businesses primarily innovate by adopting innovations developed by other businesses or organisations, with little or no additional changes to adapt the innovation to their own requirements.
5. *Non-innovators:* report no innovative activities at all.

These categories can be constructed from innovation survey data on who develops the innovation, R&D investments, markets, the novelty of their innovations (new to business only, new to market, new to world) and other survey questions that capture the internal innovation capabilities of businesses. For Viet Nam, it could be useful to expand the two categories of modifiers and adopters into three categories that provide more details of each firm's innovation capabilities and absorptive capacity, with the latter defined as the ability to identify, understand and apply knowledge obtained from sources outside the firm.[67] In addition, the category of non-innovators could be divided into potential innovators (considered innovating, but were blocked by one or more obstacles), and non-innovators. A recent study by Eurostat developed and tested, using CIS data, six main profiles plus sub-categories for each main profile.[68]

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[65] Arundel and Hollanders, 2005; see also the 4th edition of the Oslo Manual, p 82, paragraph 3.62.

[66] See: Arundel, 2007; Peneder, 2010, Hagén, undated.

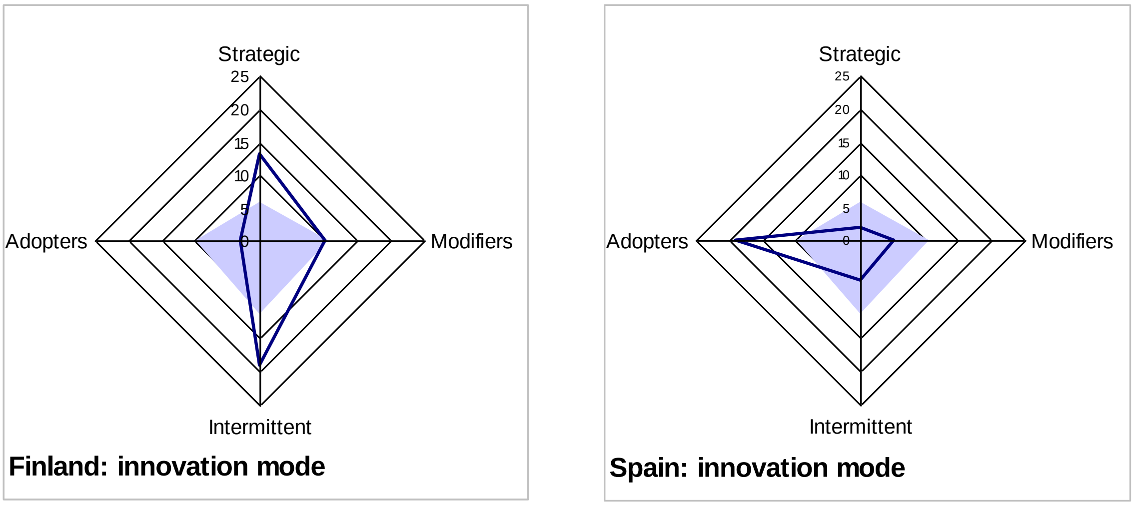
[67] Cohen and Levinthal, 1990.

[68] Eurostat, 2019.

The policy goal for profiles is to increase the capabilities of businesses or public sector agencies. For instance, the goal is to move some businesses that are non-innovators into one of the other innovation categories, or move adopters into the class of modifiers. Each change up represents an increase in capabilities. Profiles are especially useful for tracking innovation capabilities across all businesses in all sectors, in contrast to focusing on R&D intensive businesses in high technology sectors.

Figure 1 provides an example of innovation profiles for businesses for two European countries, Finland and Spain, in 2000. The results are charted on a radar diagram. The vertical axis gives the percentage of all businesses that are strategic or intermittent innovators (higher capability innovators that perform R&D on a continuous or occasional basis), while the horizontal axis gives the percentage of modifiers or adopters (lower capability innovators), as defined above. The percentages sum to less than 100%, with non-innovators (not included in the chart) making up the difference. The light blue area in the center of the charts equals the average distribution for 15 European countries.

Figure 1 Innovation profiles (mode) for the manufacturing sector in Finland and Spain, CIS data for 2000



Source: Arundel and Hollanders, 2005.

One can see at a glance that innovative businesses in Finland mostly fall in the vertical axis, with approximately 14% of all businesses being strategic innovators and 14% being intermittent innovators. In contrast, less than 5% are adopters only and 10% are modifiers. This is in sharp contrast to Spain, where the most common profile is for adopters, accounting for 19% of all businesses. Only 2% of businesses in Spain are strategic innovators and approximately 6% are intermittent innovators. In addition to increasing the percentage of businesses in Spain that are strategic innovators, an important goal for policy is to provide incentives for adopters to develop modifier capabilities and the modifiers to develop intermittent capabilities. With a few exceptions, it is very unlikely that adopters would be able to jump to the status of a strategic innovator without first developing the capabilities of modifiers or intermittent innovators.

To be useful, many business sector indicators need to be provided, at a minimum, for ISIC one-digit level sectors and for sectors in manufacturing at the two-digit level. Indicators such as R&D are dependent on the industry structure. Appendix A gives an example of estimating the feasibility of R&D intensity targets for Europe, which shows the importance of industry structure.

Business sector indicators are often based on counts and percentages of the number of businesses that undertake a defined activity. The disadvantage of these indicators is that they provide more weight to small businesses than to large businesses, since businesses of all sizes are counted equally. The alternative is either to provide these indicators for specific business size classes (less than 10 employees, 10 to 49 employees, 50 to 249 employees, 250 + employees) or to provide employment-weighted indicators. The latter are interpreted as the percentage of employees that work in businesses with a defined activity.

Table 7 refers to numbers and percentages, but it is very important to keep in mind that these results should either be presented for different business size classes or on an employment weighted basis. All indicators should be calculated for a defined period, which is one year for most indicators. The exception is innovation indicators, which can be calculated for either 1, 2, or 3 year observation periods.[69]

[69] For a discussion of observation periods in innovation surveys, see the 4th edition of the Oslo Manual, section 9.2.4.

Table 7 **Recommended Indicators for the Goods and Services Producing Sectors (all indicators are per year, except for the innovation indicators)**

Recommended Indicators for the Goods and Services Producing Sectors (all indicators are per year, except for the innovation indicators)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale / goal**
Human resources[2]	Average percentage of employees with a tertiary degree (can be disaggregated to STEM and relevant social sciences degrees), by sector.	Skills needed for some types of innovation (organizational, business models, services) and for the successful commercialisation or internal use of all types of innovations.	Absolute % increase per year	Essential skills for innovation. Target setting requires information on industrial structure and age cohorts.
"	Average percentage of employees receiving employer-sponsored training, either in-house or by other educational providers.	Continual improvement of skills of older cohorts is necessary to improve the innovative capabilities of businesses.	Absolute % increase per year for employees.	Target depends on current skill levels. A minimum level of the number hours of class time is required. There is an unknown optimum level.
"	Percentage of businesses that sponsor training by business size class (0 – 9 employees, 10 – 49 employees, 50 – 249 employees, 250+ employees).	Training can vary substantially by the resources available to businesses, which is correlated with business size.	Absolute % increase per year by business size category.	Target depends on current rates.
"	Percent domestic / all businesses by size and sector that employ individuals with skills in 'how to' innovate or used consulting services to obtain these skills.	Essential capabilities for in-house innovation	50% of innovative businesses with over 10 employees.	Innovation can occur without internal capabilities (ie. through technology adoption), so 50% is a reasonable target over 5 to 10 years.
"	Percent domestic / all businesses by size in manufacturing and industrial sectors that employ individuals with engineering degrees.	Essential capabilities for in-house innovation.	80% of innovative businesses in manufacturing / industry with over 10 employees.	Target will vary depending on the salary cost and supply of engineers.
Innovation investments[1]	Total expenditures on R&D, plus indicators for 1) expenditures funded in-house and 2) by other sources.	Input to the creation of new or improved products and processes.	Depends on current baseline and industry	Rate of growth is expected to gradually exceed the GDP growth rate.

Recommended Indicators for the Goods and Services Producing Sectors (all indicators are per year, except for the innovation indicators)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale / goal**
	Business sector R&D intensity; all sectors	Input to the creation of new or improved products and processes.	0.1 percentage points per year	This is ambitious and based on Korean and Chinese experience
	Business sector R&D as a percentage of Gross Expenditures on R&D (GERD)	To be effective, most R&D needs to be conducted by businesses and not in the public research sector.	40% by end of 10 years	Currently very low, so can't expect to achieve 70% in 10 years.
"	Percent businesses by size and sector that perform R&D on an occasional or continuous basis	Input to the creation of new or improved products and processes.	Depends on current baseline and industry	Measure of advanced innovation capabilities
"	Capital expenditures on all types of new equipment for innovations	Major form of innovation by adoption, relevant to processes and product quality, can standardize per 1,000 employees or unit of value added for specific sectors.	Depends on current baseline and industry	Major method of innovating
"	Capital expenditures on ICT hardware and software	Major form of innovation by adoption, relevant to processes and product quality, can standardize per 1,000 employees or unit of value added for specific sectors.	Depends on current baseline and industry structure	Major method of innovating
"	Capital expenditures on environmental equipment to reduce pollution, including equipment to reduce carbon emissions	Can calculate as a share of total capital expenditures on equipment	Depends on current baseline and industry structure	Major method of eco-innovation and subsequent social and environmental benefits
IP[4]	Number of patents granted via PCT or at the EPO, USPTO, JPO, or SIPO;	Foreign patents are a good measure of patent quality. Need to subdivide into grants to domestic businesses and foreign owned businesses.	Depends on current baseline	Will only be relevant to export-oriented businesses, so target expectations should be low.
"	Number of other forms of IP, particularly industrial design registrations and plant breeder rights.	These two forms of IP are close to market, unlike patents. Need to subdivide into grants to domestic businesses and foreign owned businesses.	Depends on current baseline and industry structure	Also relevant to the domestic market, but target expectations should be low.

Recommended Indicators for the Goods and Services Producing Sectors (all indicators are per year, except for the innovation indicators)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale / goal**
"	Number of patents, industrial designs, and plant breeder rights per 1,000 employees.	Standardized indicator for comparison across sectors.	Depends on current baseline and industry structure.	Also relevant to the domestic market, but target expectations should be low
Government policy[2] support	Percent domestic / all businesses by size category and sector that received government support for innovation (by type of support if possible)	Identify sectors / areas where government support not effective in reaching targets	Depends on policy goals	Inform innovation policy
"	Percent domestic / all businesses by size category and sector that have a tender to supply goods or services to government (procurement) and if yes, the percent of procurement contracts that require innovation to meet the tender specifications.	Determine if procurement is creating demand for innovation.	Should reach 25% to 50% of procurement contracts for SMEs.	Inform procurement policy
Trade[4]	Value added share of exports by sector; change in value added share	Measure upgrading of Vietnamese businesses in international supply chains	30% of exports in manufacturing	Goals may also need to be sector specific
Innovation[2]	Percent domestic /all businesses by size and sector with one or more innovations over a two or three year period.	Basic innovation indicator, but only of low value.	Should reach 50% of all businesses and 90% of businesses with more than 250 employees within 10 years.	Goals may also need to be sector specific
"	Percent domestic / all businesses by size and sector within each of 4 to 5 profiles for innovation capability.	High value innovation indicator for assessing development of innovation capabilities across the economy.	For all businesses: 10% high capability, 30% moderate capability, 10% low capability.	Additional sector specific goals may be needed
Notes for sources of indicators 1: R&D survey 2: Business innovation survey				

Recommended Indicators for the Goods and Services Producing Sectors (all indicators are per year, except for the innovation indicators)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale / goal**
3: Knowledge Transfer Office survey 4. Administrative data (patents, trade, etc.)				

4.4 Recommended Indicators for Knowledge Exchange

Knowledge exchange is a key function for the research sector that involves transferring discoveries and knowledge to potential users in the business sector. It also includes collaboration within each sector and with international partners. Table 8 lists indicators for knowledge exchange that should be collected on an annual basis.

As noted in Part 1 in the section on knowledge transfer, the most common indicators for knowledge exchange concern formal methods, particularly patent licensing. This is largely because of data availability and does not reflect the importance of informal knowledge exchange (meetings, conferences, etc.) or other contractual methods, such as consulting and contract research. In fact, informal and contractual methods are of greater importance to knowledge exchange than patents in all medium and high-income countries for which data are available.[70]

Consulting is a particularly valuable method in middle-income countries and is likely to be (or should be) widely used in Viet Nam, followed by contracting. Knowledge exchange via licensing patented discoveries made in the research sector are unlikely to play much of a role until Viet Nam has a developed domestic manufacturing industry with multiple businesses performing R&D. Consequently, policy must be careful not to favour the use of patent licensing over other methods of knowledge exchange that are better suited to assist businesses with limited research capabilities.

Foreign Direct Investment (FDI) is a potential source of knowledge exchange, particularly spillovers from production plants and research centers to domestic businesses. The 2019 World Bank report on Viet Nam noted that FDI accounts for a high share of R&D and value-added in Viet Nam, but that there are few policies to promote spillovers. Policy development would benefit from indicators on the amount of R&D in Viet Nam that is conducted by foreign-owned businesses, the amount of R&D in the public research sector that is funded by foreign-owned businesses, and spillovers to domestic businesses from foreign-owned businesses through technical assistance, consulting and other methods. Identifying spillovers is likely to require adding relevant questions to an innovation survey.

[70] See the six country chapters in Arundel et al, 2021.

Table 8 Recommended Indicators for Knowledge Exchange (all indicators are per year, except for the innovation indicators)

Recommended Indicators for Knowledge Exchange (all indicators are per year, except for the innovation indicators)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale / goal**
Bibliometrics: international	Average number of public research sector SCI or SSCI publications with one or more co-authors located outside Viet Nam.	International collaboration encourages inflow of expertise and knowledge to Viet Nam. Should be averaged over research disciplines and published for each university / research institute.	Universities: 0.5 per FTE researcher, research institutes: 0.25 per FTE researcher.	Improve inflow of knowledge.
R&D[1]	Percent researchers at universities / public research institutes that are partners in research projects with participants from foreign universities / research institutes	Participating in international research projects can improve the capabilities of domestic researchers	5%	Need to know current state before setting target
"	Share of research by universities / research institutes funded by foreign sources	Only very high quality research will be funded from foreign sources – therefore a measure of research quality. Also, often combined with research collaboration.	2%	Need to know current state before setting target
"	Percent university researchers / public research institutes in STEM disciplines with advanced degrees (Masters or PhD) obtained at leading universities abroad.	Can define leading universities using the QS World Ranking or the ARWU world ranking. A cut-off can be drawn for the top 500 or top 1000. This is a mid-term indicator until Viet Nam develops its own leading universities. Researchers who obtain advanced degrees abroad will have had access to leading equipment, teaching methods (which they can use in Viet Nam), and exposure to knowledge transfer activities.	15%	Need to know current state before setting target, plus government policies to subsidize/encourage students to obtain advanced degrees abroad / return to Viet Nam.
IP[2]	Percent domestic/ all businesses by size and sector that license IP from Vietnamese public research sector	IP mediated method of knowledge exchange.	3% of innovative businesses over a	May only be worth setting goals for specific sectors.

Recommended Indicators for Knowledge Exchange (all indicators are per year, except for the innovation indicators)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale / goal**
	(patents, copyright, knowhow, plant breeders rights, industrial designs).		two to three year time period.	
Innovation[2]	Percent domestic/ all businesses by size and sector that collaborate with other businesses on innovation.	Collaboration increases access to knowledge, reduces risk, and improves capabilities. This indicator could be produced by web-scraping.	30% for innovative businesses.	
"	Percent domestic/ all businesses by size and sector that obtain research services from the Vietnamese public research sector via consulting or research contracts.	Key method for knowledge exchange with the research sector.	10% of innovative businesses over a two to three year observation period.	
"	Percent domestic businesses / all businesses by size and sector that collaborated on innovation with organisations outside Viet Nam	International collaboration; method for building domestic capabilities. This indicator could be produced by web-scraping.	5% of innovative businesses over a two to three year observation period.	
KT office[3]	Percent universities and research institutes with access to the services of a knowledge transfer office (KTO)	Access to a high quality KTO is necessary for full exploitation of commercially valuable knowledge	100% at end of decade.	
"	Percent KTOs with professional evaluators of invention disclosures and licensing opportunities with private sector experience	Public servants are not good at this role – professionals with private sector experience are essential.	100% at end of decade.	
"	Financial incentives for research staff to disclose inventions / collaborate with businesses in developing the invention	Some inventions will never be developed without assistance from the inventor	100% of universities and research institutes	This may conflict with other policies, but research in multiple countries shows that financial incentives are the most effective.

Recommended Indicators for Knowledge Exchange (all indicators are per year, except for the innovation indicators)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale / goal**
“	Number of invention disclosures reported by universities and public research institutes to KTOs; number per 1,000 FTE researchers	Invention disclosures are the basic material for identifying discoveries with commercial potential	10 per 1,000 FTE researchers per year[5]	
“	Number of consultancies and research contracts with businesses; number per 1,000 FTE researchers; disaggregated into domestic and all businesses	Most effective method of transferring knowledge	20 per 1,000 FTE researchers as a minimum	Need to know current state and relevant policies before setting target
“	Number businesses / income derived from businesses using facilities and equipment related services provided by universities / research institutes	Effective method of supporting R&D capabilities of businesses		Need to know current state and relevant policies before setting target, plus will vary by types of facilities available
“	Number of employees from businesses that took professional development / continuing education courses at the university or research institute	Effective method of supporting R&D capabilities of businesses		Need to know current state and relevant policies before setting target
“	Number of events held by KTO to link researchers and businesses	Informal contacts can lead to further linkages	2 per month as a minimum	Need to know current state and relevant policies before setting target
“	Number of IP licenses (all types of IP); per 1,000 FTE STEM researchers	Secondary measure of knowledge transfer	2[5]	Need to know current state and relevant policies before setting target
“	Number of start-ups / spin-offs established; per 1,000 FTE STEM researchers	Effective method of transferring knowledge to regions	0.5[5]	Need to know current state and relevant policies before setting target
“	Percent universities / research institutes with dedicated facilities to support	Startups / spinoffs often require support for early stage development.	25%	Need to know current state and relevant policies before setting target

Recommended Indicators for Knowledge Exchange (all indicators are per year, except for the innovation indicators)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale / goal**
	startups/spinoffs such as an incubator or science park.			
	Percent STEM researchers at universities / public research institutes that reported an invention disclosure /applied for a patent or other form of IP that are currently or had been (in the last 3 years) temporarily employed at a business (staff exchange)	Moving academics to businesses as part of a temporary exchange is often necessary to transfer tacit knowledge associated with an invention or patent.	5%	Depends on laws facilitating staff exchanges.
"	Total income earned from all forms of knowledge transfer	Benefit to public research sector	5% of total research expenditures in sector	Best practice in the world for IP income from licensing alone is the US at 4%.
FDI[2]	Number / percentage of domestic suppliers to foreign owned businesses that receive training to upgrade employee skills from foreign-owned client businesses.	Direct spillover of capabilities via FDI. This indicator could be produced by web-scraping.		Need to know current state and relevant policies before setting target
	Number / percentage of domestic suppliers to foreign owned businesses that receive assistance with equipment upgrades skills from foreign-owned client businesses.	Direct spillover of capabilities via FDI		Need to know current state and relevant policies before setting target

Notes for sources of indicators

1: R&D survey

2: business innovation survey

3: KTO survey

4. Administrative data (IP, trade, etc.

Recommended Indicators for Knowledge Exchange (all indicators are per year, except for the innovation indicators)				
Indicator Family	**Description of base indicator**	**Rationale**	**Targets**	**Target rationale / goal**

5: Target based on approximately 1/3 of performance of approximately 500 European universities and public research institutes combined over 2011 and 2012 (Arundel et al, 2013).

5 Appendix A: Example of estimating targets for business R&D

Excerpted from: Arundel, A. and Hollanders, H., 2005. EXIS: An exploratory approach to innovation scoreboards. *European Trend Chart on Innovation*.

Targets for Business R&D Expenditures

The European Union in the early 2000s set a target for a 3% R&D intensity across the European Union by 2015, based on 33% of the R&D expenditure coming from the public sector and 66% from the business sector, giving a 2% goal for business expenditures on R&D (BERD) and 1% for government expenditures on R&D (GOVERD). The challenge in estimating future BERD levels is to account for very large sector differences in BERD, which range from under 1% in food processing, tourism and textiles, 3% - 4% in automobiles, and to over 10% in pharmaceuticals and aerospace. Similar differences occur in services. For this reason, the observed R&D intensity of a specific country is strongly influenced by the distribution of economic activity by sector. A country with an industrial structure based on food processing, tourism and textiles will have a much lower R&D intensity than a country with large automobile, pharmaceutical and IT services sectors. This is likely to remain the case even if the country based on food processing and tourism has the highest observed R&D intensities for those sectors.

To account for sectoral differences in R&D intensities, this study estimated national R&D intensities into the five year (2010) and ten year (2015) future compared to the date of the study in 2005. The estimates were constructed from the most recent data on R&D expenditures by sector (2002 or 2003), using the OECD ANBERD database. Data were available for only 13 of the 25 EU member states in 2005, but these 13 countries accounted for 95.4% of total BERD among the EU 25 countries in 2002 and 93% of GDP. Therefore, the ability of the EU to reach the 2% Barcelona target for BERD almost entirely depended on business R&D in these 13 countries.

Table A1 gives an example for selected manufacturing sectors for Germany. For most sectors, R&D data were available at the two-digit NACE level, but three-digit results are also available for some countries. For instance, R&D data for Germany is available at the three-digit level for aircraft (353).

The 2003 results are for observed R&D expenditures in Germany, while the results for 2004 and 2010 are estimated, using the average rate of change for BERD in Germany by sector over the preceding six years (1998 – 2003 inclusive). The total BERD for Germany in 2010 is obtained from the sum of the estimates over all manufacturing, industrial, and service sectors[71]. The estimates for the 'best possible case' used the highest observed R&D growth rates for 11 advanced countries, while the results for Poland and the Czech Republic used the highest observed growth rates among all 13 countries. The limitation for the 11 advanced members of the EU-15 is due to exceptionally high growth rates in some sectors in Poland and the Czech Republic that were unlikely to be sustainable in more developed economies.

[71] BERD is not available for several low R&D intensity sectors such as agriculture, fishing, and quarrying. As the analysis consequently excludes GDP for these sectors, the results slightly overestimate European BERD intensity.

Table 1A. Example of sector specific BERD estimates for Germany (million USD PPP), based on past growth rates for Gemany (basic trend)

Nace		2003 (Observed)	2004 (Estimated)	2010 (Estimated)
29...35	Machinery and equip., instrum. and transp. eq.			
30	Office, accounting and computing machinery	588.4	589.3	544.3
31	Electrical machinery and apparatus nec	1116.4	1232.5	1400.6
32	Radio, TV and communication equipment	3653.6	3887.5	4049.9
29	Machinery and equipment nec	4182.0	4304.5	5378.5
33	Instruments, watches and clocks	2343.5	2766.9	3697.3
34	Motor Vehicles	11337.6	12674.8	15127.0
35	Other transport equipment			
351	Building and repairing of ships and boats	62.5	59.6	102.1
353	Aircraft and spacecraft	2424.2	2129.0	2608.4
352+359	Railroad and other transport equipment nec	434.4	415.8	664.7

Estimates of GDP for each country are obtained from extrapolation, using the average growth of GDP over the previous six years. GDP estimates were not adjusted for possible changes in the growth rate that could be caused by shifts in industrial distributions[72]. However, because GDP was assumed to grow at a constant rate, shifts in industrial distributions occur due to changes in the sector growth rates of BERD. In the example for Germany, BERD in the office equipment sector falls by 7.5% from 588 million in 2003 to 544 million in 2010, indicating a decline in the economic output of this sector, while BERD in the automobile sector increases by 33.4%, marking an increase in economic output. The final estimates of business R&D intensity are obtained by dividing the total estimated BERD in 2010 and 2015 by the estimated GDP for each year.

Table 2A gives the basic 'business as usual' estimate, using national growth rates, and the maximum 'best case' estimate, using the highest sector growth rates for the 13 countries for which R&D data by sector are available. Using current national growth rates by sector, the BERD intensity for the EU-13 would only reach 1.31% in 2010 and 1.35% in 2015 – far below the goal of 2%. Only four countries would reach or exceed 2%: Belgium (2.15%), Denmark (2.77%), Finland (2.85%), and Sweden (3.28%). There is very little expected improvement in BERD intensities in four countries (Czech Republic, Italy, the Netherlands, and the UK) while BERD would decline in Poland and Ireland.

The EU could only achieve a BERD intensity of 2% by 2015 if the R&D intensity of all sectors in all countries grew at the highest growth rate observed in each sector. This was highly unlikely. Even under these assumptions, the BERD intensity for Italy barely exceeded 1% (1.02%), which was primarily due to an industrial structure dominated by sectors with low R&D intensities. The expected BERD intensity of Spain also remained below 1% (0.88%) for the same reason.

[72] One effect is that the results given here probably overestimate BERD intensity, since a faster GDP growth rate would depress BERD as a percentage of GDP.

Table 2A. Estimated BERD/GDP in 2010 and 2015

		2010		2015	
	Baseline 2002	**Basic**	**Maximum**	**Basic**	**Maximum**
Belgium	1.63	2.00	2.53	2.15	2.88
Czech Republic	0.77	0.77	1.03	0.79	1.15
Denmark	1.75	2.45	2.79	2.77	3.25
Finland	2.46	2.75	3.20	2.85	3.53
France	1.43	1.60	2.09	1.67	2.31
Germany	1.73	1.83	2.63	1.87	3.13
Ireland	0.79	0.72	0.89	0.70	0.91
Italy	0.55	0.58	0.85	0.60	1.02
Netherlands	1.02	1.07	1.60	1.08	1.79
Poland	0.12	0.04	0.19	0.03	0.21
Spain	0.56	0.66	0.81	0.70	0.88
Sweden	2.95	3.22	4.18	3.28	4.81
United Kingdom	1.26	1.29	1.79	1.31	1.97
EU-13	*1.22*	*1.31*	*1.78*	*1.35*	*2.02*

On the basis of these results, we concluded that the 2% BERD intensity goal was unrealistic and unachievable by 2015. It would require massive and economically painful changes in the structural distribution of sectors within Europe.

The lessons for Viet Nam are that goals for R&D intensity must reflect the current industrial distribution of the Vietnamese economy, expectations for changes in the industrial distribution into the future, including the creation of entirely new sectors, and expectations for changes in value-added in each sector. High levels of value-added are required to produce a surplus for investment in R&D, creating a virtual cycle of R&D investment followed by further increases in value-added.

6 References

Alves, H. (2013). Co-creation and innovation in public services. *The Service Industries Journal*, 33:671-682.

Ahmad, N., & Ribarsky, J. (2018). Towards a framework for measuring the digital economy. In *16th Conference of the International Association of Official Statisticians*. September.

Arundel, A. (2007). Innovation survey indicators: What impact on innovation policy. In Arundel, A., Colecchia A., Gault, F. (Eds.) *Science technology and innovation indicators in a changing world: Responding to policy needs*, pp.49-64, OECD, Paris.

Arundel, A., Athreye S. and Wunsch-Vincent, S. (Eds.), (2021) Harnessing Public Research for Innovation in the 21st Century, Cambridge University Press, Cambridge.

Arundel A, Barjak F, Es-Sakdi N, Barjak F, Perrett P, Samuel O, Lilischkis S, (2013). *Knowledge Transfer Study 2010-2012*, 385 pp. Report for DG Research and Innovation, Brussels, June. ISBN 978-92-79-32388-1.

Arundel, A., Bloch, C., & Ferguson, B. (2019). Advancing innovation in the public sector: Aligning innovation measurement with policy goals. *Research Policy*, *48*(3), 789-798.

Arundel, A., Casali, L., & Hollanders, H. (2015). How European public sector agencies innovate: The use of bottom-up, policy-dependent and knowledge-scanning innovation methods. *Research Policy*, *44*(7), 1271-1282.

Arundel, A., Colecchia, A. and Wyckoff, A., 2006. 9. Rethinking science and technology indicators for innovation policy in the twenty-first century. In Earl L. and Gault F. *(Eds) National innovation, indicators and policy*, pp 167-198, Edward Elgar, Cheltenham.

Arundel, A., Es-Sadki, N. Toward a Comprehensive Set of Metrics for Knowledge Transfer, in Wunsch-Vincent, S., Arundel, A., Athreye S. (Eds.), Harnessing Public Research for Innovation in the 21st Century, Cambridge University Press, 2021.

Arundel A, Hollanders H. EXIS: An Exploratory Approach to Innovation Scoreboards, TrendChart, DG Enterprise, March 2005.

Arundel, A. and Smith, K., 2013. History of the community innovation survey. In *Handbook of innovation indicators and measurement*. Edward Elgar Publishing.

Arundel, A. and Wunsch-Vincent, S. Evaluating Knowledge Transfer Policies and Practices: Conceptual Framework and Metrics, in Arundel, A., Athreye S. Wunsch-Vincent, S., (Eds.), Harnessing Public Research for Innovation in the 21st Century, Cambridge University Press, 2021.

Belenzon, S., & Schankerman, M. (2009). University knowledge transfer: private ownership, incentives, and local development objectives. *The Journal of Law and Economics*, *52*(1), 111-144.

Calvino, F., Criscuolo, C., Marcolin, L. and Squicciarini, M., 2018. A taxonomy of digital intensive sectors, OECD.

CEC (Commission of the European Communities), 2005. *Proposal for a Decision of the European Parliament and the Council Establishing a Competitiveness and Innovation Framework Program (2007–2013)*, COM(2005) 121 Final, Brussels, April 6.

CEC (Commission of the European Communities), 2006, *Creating an Innovative Europe*. Luxembourg: Office for Official Publications of the European Communities, January. http://ec.europa.eu/invest-in-research/pdf/download_en/aho_report.pdf.

Eurostat, 2019. CIS Task Force Innovation Profiling in the EU, Based on CIS Data. Report to Working Group on Statistics on Science, Technology and Innovation, Eurostat/G4/STI/WG/2019/Document 7, November.

Chen B., Huang C., Peng C., Ding M., Huang N., Liu X., and Yang J., China Chapter, in Arundel, A., Athreye S., and Wunsch-Vincent, S. (Eds.), Harnessing Public Research for Innovation in the 21st Century, Cambridge University Press, 2021.

Cinar, E., Trott, P., & Simms, C. (2019). A systematic review of barriers to public sector innovation process. *Public Management Review*, *21*(2), 264-290.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative science quarterly*, 128-152.

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2000). *Protecting their intellectual assets: Appropriability conditions and why US manufacturing businesses patent (or not)* (No. w7552). National Bureau of Economic Research.

Cornell University, INSEAD, and WIPO, 2019, The Global Innovation Index 2019: Creating Healthy Lives—The Future of Medical Innovation, Ithaca, Fontainebleau, and Geneva.

Côté G, Stanciauskas, V. (2018) Provision and analysis of key indicators in research and innovation: Year 1 Interim data and analytical report (Innovation), Science-Metrix, Montreal, 30 October.

Edler, J. and Georghiou, L., 2007. Public procurement and innovation—Resurrecting the demand side. *Research policy*, *36*(7), pp.949-963.

Evangelista, R. and Mastrostefano, V., 2006. business size, sectors and countries as sources of variety in innovation. *Economics of Innovation and New Technology*, *15*(03), pp.247-270.

Evangelista, R., Perani, G., Rapiti, F. and Archibugi, D., 1997. Nature and impact of innovation in manufacturing industry: some evidence from the Italian innovation survey. *Research policy*, *26*(4-5), pp.521-536.

Finne H, Arundel A, Balling G, Brisson P, Erselius J. *Metrics for Knowledge Transfer from Public Research Organisations in Europe*, Report from the European Commission's Expert Group on Knowledge Transfer Metrics, DG Research, European Commission, Brussels, 2009. *https://op.europa.eu/en/publication-detail/-/publication/d0dbd13d-6b28-4398-896b-0fe9cf0ed2cb.*

Geuna, A., & Muscio, A. (2009). The governance of university knowledge transfer: A critical review of the literature. *Minerva*, *47*(1), 93-114.

Gottardi, G., 1996. Technology strategies, innovation without R&D: and the creation of knowledge within industrial districts. *Journal of Industry studies*, *3*(2), pp.119-134.

Hagén, Hans-Olof, "Innovators and business developers", IFI/ES/Statistics Sweden 2014-12-0.1.

Hawkins, R., Mansell, R., & Skea, J. (1995). *Standards, Innovation and Competitiveness*. Edward Elgar Publishing.

HEFCE (Higher Education Funding Council for England), (2017). Higher Education-Business and Community Interaction Survey 2015-6, HEFCE, London.

Kemp et al. (2019). Maastricht Manual on Measuring Eco-Innovation for a Green Economy: https://www.inno4sd.net/uploads/originals/1/inno4sd-pub-mgd-02-2019-fnl-maastrich-manual-ecoinnovation-isbn.pdf.

Lember, V., Kattel, R., & Kalvet, T. (2014). Public procurement and innovation: Theory and practice. In *Public procurement, innovation and policy* (pp. 13-34). Springer, Berlin, Heidelberg.

Lhuillery, S. and Bogers, M. (2006). Measuring user innovation: What can a standard innovation survey tell us?. *Available at SSRN 1594038*.

NESTA (2018). European Innovation Scoreboard 2018: Exploratory report B: Toward the incorporation of big data in the European Innovation Scoreboard, European Commission, Luxembourg, June 14, 2018.

OECD (2015). Frascati Manual: Guidelines for Collecting and Reporting Data on Research and Experimental Development. OECD, Paris.

OECD/Eurostat (2018). Oslo Manual 2018: Guidelines for collecting, reporting and using data on innovation, 4th Edition. OECD, Paris.

Peneder, M. (2010). Technological regimes and the variety of innovation behaviour: Creating integrated taxonomies of businesses and sectors, *Research Policy* 39:323-334.

Schwab, K., (Ed) 2019. The Global Competitiveness Report, World Economic Forum, Geneva.

Utterback, J.M. and Abernathy, W.J. (1975). A dynamic model of process and product innovation. *Omega 3*: 639-656.

Willis, G.B. (2004). *Cognitive interviewing: A tool for improving questionnaire design*. Sage publications.