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Role of Public Research Institutes in National Innovation Systems in Industrialized Countries: The cases of Fraunhofer, NIST, CSIRO, AIST, and ITRI*

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Abstract

Public research institutes (PRIs) were established for many reasons including promoting defense related research and health related research. Helping domestic industries remain as one of the important missions for PRIs even when the countries have become industrialized and firms' technological capabilities are high. PRIs aim to upgrade existing industries, especially small and medium-sized enterprises (SMEs), as well as spearheading new ones. They can conduct research to solve today's problems in the existing industries and those of next-generation technologies which may lead to the creation of new industries. Moreover, the relationship between PRIs and firms and non-firm actors such as universities became more intense, open, horizontal, international, and long term. To reduce risk and uncertainty inherent in the research mentioned above, the intermediary roles of PRIs are becoming increasingly important. The emphasis and the ways that PRIs help industry change over time and vary across countries as they are an integral part of national innovation systems. This makes generalization difficult, but the experiences of five leading PRIs in Germany, Taiwan, Japan, Australia, and the United States shows that the balances between contract research vs. longer term research with its own initiative, mobility of researchers vs. retaining core researchers, and competitive grants and funds from industry vs. block grants from governments are important in keeping PRIs relevant to industry needs and maintaining research standards. These balances depend on the nature of the national innovation system in which they are embedded. The governance of PRIs is of particular importance to maintain proper balances.

Keywords: Public research institutes, Knowledge transfer, Intermediary, National innovation systems, Industrialized countries

JEL Classification: O32 and O38

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1. Introduction

Public Research Institutes are one of the important actors in many national innovation systems. However, compared to universities, the actor on which many research has been done, it has attracted rather limited attention of innovation scholars. In this paper, we investigate the roles of five prominent PRIs whose mission is to support technological development of industry in their national innovation systems.[1]

The role of PRIs is often described by themselves as the actor that helps technology to cross the valley of death, or fills the gap between basic research and development. A hub of a national innovation system is also another favourite phrase. It might be the case that there is a need to do further research to make early stage technology usable for industrial production in many national innovation systems of advanced countries where industry is capable of conducting advanced research by themselves and one cannot assume that PRI's research capabilities are higher than those of the industry anymore. It might be the case, again, that intermediating actors is not sufficient even in national innovation systems accompanied by well- developed market economy. With the increasing speed of technological change, growing need for wider research base, and increasingly intense global competition, industry might find it useful if PRIs can help their research and development.

However, how to operationalize these concepts into actual design and operational procedure of PRIs is the most important task. Without this, these are simply catch-phrases to rationalize whatever PRIs and their researchers are currently doing. Each national innovation system has unique characteristics, and unique evolutionary process. Therefore, PRIs in each national innovation system has its own role, unique way to fulfil its functions mentioned above, reflecting the different characteristics of national innovation systems.

[1] PRIs are established for many missions such as to promote defence technology, health research, energy research, and so on. These PRIs help industries technologically significantly. However, we focused PRIs whose mission is to help broad industrial technology.

To answer this important question, we studied five world renowned PRIs; Fraunhofer-Gesellschft (FhG) in Germany, National Institute of Standards and Technology (NIST) in the United States, National Institute of Advanced Industrial Science and Technology (AIST) in Japan, Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia, and Industrial Technology Research Institute (ITRI) in Taiwan, to understand mechanisms to make PRIs effective instrument for innovation. These PRIs were selected because they were globally recognized, long established, large and had an explicit mission to help industries and located in typical industrialized countries like the US, Germany, Japan, Australia and Taiwan. In-depth and semi-structured interviews of these five institutes were conducted during September 2013 to February 2016. Secondary data were also collected from institutes' reports and previous studies.

Public research institutes are quite diverse within and across countries. Their activities vary widely according to their mission and type. Some perform "blue sky" science or basic research that often has a long time horizon and carries high risks with uncertain returns, while others focus on more short term market-oriented research, development work, problem solving and technical assistance (OECD, 2011). In our study, we focused those PRIs whose main mission is to promote innovation in private sector. Although large and famous PRIs like National Institutes of Health (NIH) and defence- related PRIs in the US, that conduct massive, basic, mission oriented research have substantial spillover effect (including human resource development and spin off), they are not included in our study.

As mentioned before, research on PRIs is rather limited compared to that on universities. However, there are a few interesting early research on PRIs. According to Bell(1993), United States during the catch-up period, PRIs accounted only 15 % of all R&D scientific professionals in the early 1920s, and 6 per cent in the mid-1940s. PRIs originated and grew 'incrementally' in response to industry's industrial and technology demands. Later, when the US was closer or at technological frontiers, more PRIs were set up in new areas like aerospace, defence, and telecommunications and some of these institutes started to research on areas relatively independent to industry.

In industrializing countries successful in technologically catching up, PRIs helped firms to enhance their absorptive capacity in identifying, evaluating, assimilating, and upgrading technologies already existed elsewhere (Intarakumnerd, 2011). In both industrialized and industrializing countries, PRIs can play important roles not only in creating new knowledge and transfer to firms, but also acting as 'intermediaries'. Lente et al. (2003) consider PRIs as a new type of intermediary organisation that functions at a system or network level, in contrast to traditional intermediary organisations that operate mainly bilaterally. These 'systemic intermediaries' are important for long-term and complex changes, such as the transition to sustainable development, that require more systemic efforts to articulate needs and options, the alignment of relevant actors and the support of learning processes. More specifically, Dodgson and Bessant (1996) proposed that PRIs can perform particular activities bridging the demand (user needs) and the supply side (resources) in innovation processes, such as articulation of specific needs and bridging links with outside knowledge system. As nature of innovation is more *open* today, roles of PRIs in linking various actors such as users, producers, and other stakeholders can be expected even more. In short, PRIs can help to solve 'systemic failures' that might slow down or even block interactive learning in innovation systems[2].

Concerning PRIs' success factors, Rush *et. al* (1995) studied eight PRIs in eight countries, both developed and newly industrialized. The success factors can be classified as internal (under direct control of PRIs), external (outside control of PRIs), and negotiated (affected to a lesser or greater extent by PRIs)

[2] Detailed studies on systemic failures can be found in Woolthuis (2005), Chaminade, and Edquist (2006), and Foray (2009).

- Internal factors: leadership, defined strategy, flexible structure, training, technical competence, project management, personnel management, good communications, technology search
- External factors: stable policy, consistent funding, demanding users, government commitment, macro-economic growth, industrial development
- Negotiated factors: industrial input, market responsiveness, networking, learning from firms, links to policy making, links to universities and image and awareness

More recently, based on surveys and 12 cases studies of public research institutes, Organization for Economic Cooperation and Development (OECD, 2011) identified important trends. Some of them are similar to issues identified by Rush (1995)

- Country-level evidence highlighted the strong focus on applied research. Nonetheless, broader public-oriented missions appeared more common than industry-oriented one. There were also increases in 'trans and multi-disciplinary sciences'.
- Structures and governance have evolved to engage more stakeholders. Public research institutes tried to adopt more business-like operational models and public-private partnerships, and increased openness and market responsiveness.
- Funding has become increasing competitive. 'Block' grants from government were conditioned by performance. Public research institutes have to rely more on 'competitive' channels of funds, and incomes from industry and abroad. In essence, funding issues demand instruments which balance short-and long-term goals and requirements of different users, uphold research quality and ensure sustainability of activities.
- Human resources remain major input but public research institutes are facing considerable challenges in recruiting, maintaining, rewarding and motivating research staff.
- Linkages with other players and internationalization have increased. 'Personal interaction' is important for both linkages with universities and firms.

- Effective steering and governance is essential to ensuring relevance of public research institutes. Evaluation of performance against stated goals of increases autonomy, collaboration and responsiveness to stake holder should be encouraged.

The abovementioned previous studies on roles and success factors of PRIs in industrialized countries are interesting and useful. The question is how these roles and factors can be created or facilitated. To answer this question, we will investigate roles of five PRIs and try to find the factors determining their success (or failures) in details in the following section.

The article is set out as below. Section 2 examines the roles and evolution of five case-studied PRIs, namely, Fraunhofer, NIST, CSIRO, AIST and ITRI. Based on these case studies, section 3 discusses crucial aspects concerning strategies and management of PRIs in industrialized countries: research agenda setting, finance, attracting and managing researchers, intermediating roles, and performance evaluation. Finally, conclusion and policy implications for other PRIs in industrialized countries will be highlighted in Section 4.

2. Roles and Evolution of Public Research Institutes in National Innovation Systems in Five Selected Cases

2.1 Fraunhofer Institute (Germany)

Started in 1949, Fraunhofer- Gesellschaft (FhG) is now Europe's largest applied non-profit research institute. With a workforce of over 22,000, the institute currently operates a total of 66 institutes and independent research units ("Fraunhofer Institute", n.d.). FhG had a clear mission from the beginning i.e., to carry out research of practical utility in close cooperation with its customers from industry and the public sector. Its research efforts are geared entirely to people's needs: health, security, communication, energy and the environment. Administratively, FhG has enjoyed high autonomy in management. There is no government intervention in selecting research projects and its performance evaluation is based on overall contribution to Germany's economy (not project by project). Government has a certain level of authority in selecting FhG's president but less than institutes in other countries, as board members are also from industry and academic.

Budget-wise, government only provides basic fund of 1/3 of total R&D project's budget. Another 2/3 must come from industry, government competitive grants or other sources like EU. This is a very strict criterion for evaluating performance of its R&D institutes. Moreover, FhG incentivized their institutes working with the industry by providing more basic fund to those that could attract more contributions from external sources. Both FhG's governing council and advisory board of each individual institute have representatives of both industry and academic world.

The most important formal interactive mode with the industry is contract research. This ensures that FhG's research is very much industrial relevant. Half of contract research came from large companies, while the other half were from SMEs. Spin off and licensing are secondary, though the number of spin-off firms (around 200 until 2012) and licensing revenues (117 million Euro in 2012) were not small. Informal channels also play a significant role. The most 'informal' mode of interaction is mobility of FhG's researchers to industry. This has been implemented deliberately, as 60 percent of researchers work for fixed-term contract of 3-5 years. Subsequently they had to seek jobs in the industry. The institute manages 'alumni' database. Many alumni keep contacting with FhG and bringing back collaboration with firms they are currently working for. Region-wise, FhG adopted geographical concept by working with local industries and universities in the fields based on specialization of particular geographical areas. For example, the Fraunhofer Institute for Integrated Systems and Device Technology (IISB), founded in 1985, conducts applied research and development in the fields of micro- and nanoelectronics, power electronics, and mechatronics. It is co-located in Erlangen together with the University of Erlangen whose Chair on Electron Device being affiliated with FhG, and a Siemens's R&D laboratory. Similarly, the Fraunhofer Institute for Manufacturing Engineering and Automation IPA was founded in 1959 to carry out research on organizational and technological issues in the manufacturing environment of advanced industries, including automotive and other industries. The institute is co-located with University of Stuttgart and R&D laboratories of giant German firms in the automotive industry.

FhG also acts as intermediary between universities and firms. Most of its R&D institutes are located in universities. Directors of these institutes mostly have titles of professors. Most came from universities, while some were from industry (after being a director of an institute, he or she would be appointed as a university professor). Undergraduate students can start engaging with FhG's institutes as research assistants, and continue working during their Master degree and Ph.D. After graduation, they are allowed to carry on their work for a fixed year period of 3-5 years before leaving for the industry.

Recently, FhG has tried to use its own saved fund to conduct more research having longer-term goals and strategic purpose for the future and not being interested by the industry. Nonetheless, this is still rather small, as most of basic research has been carried out by Max Plank Institute (D. Kaske, personal communication, September 9, 2013), a basic research institute. This reflects division of labor between research technology organizations in Germany. In addition, as knowledge network became more globalized, FhG set up branches in the US, Japan and China to work with excellent foreign entities (firms, universities, research technology organizations).

2.2 National Institute of Standards and Technology or NIST (United States)

Founded in 1901, NIST is a non-regulatory federal agency within the U.S. Department of Commerce. Initially, it was National Bureau of Standards (NBS) established by Congress. NIST's mandate can go back to the article I section 8 of US's constitution, which stipulate that ‘the congress shall have the power to fix the standard of weights and measures’. At the time of establishment, the US was trailing Britain and Germany in standard and measurement. American instruments were sent abroad for calibration. Consumer products and construction materials were uneven in quality and unreliable. The emerging industry, especially the electrical one, strongly needed standard. Later, NBS was moved from Washington D.C. to Gaithersburg in 1966 and became NIST in 1988.

NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing *measurement science, standards, and technology* in ways that enhance economic security and improve our quality of life. NIST carries out its mission through the following four main programs:

- the NIST Laboratories, conducting world-class research, often in close collaboration with industry, that advances the nation's technology infrastructure and helps U.S. companies continually improve products and services;
- the Hollings Manufacturing Extension Partnership (MEP), a nationwide network of local centers offering technical and business assistance to smaller manufacturers to help them create and retain jobs, increase profits, and save time and money;
- the Baldrige Performance Excellence Program (AMTech), which promotes performance excellence among U.S. manufacturers, service companies, educational institutions, health care providers, and nonprofit organizations; conducts outreach programs; and manages the annual Malcolm Baldrige National Quality Award which recognizes performance excellence and quality achievement;
- The Advanced Manufacturing Technology Consortia Program (ATP), which support industry-led consortia to develop common technological vision and accelerate innovation.
- In addition, from 2007 to 2011, NIST provided cost-shared grants through the Technology Innovation Program, and between 1990 and 2007, it managed the

Advanced Technology Program ("National Institute for Standards and Technology", n.d.).

In general, NIST has a certain degree of freedom to decide on research topics, but not to the same extent as NSF-funding research. It tries to balance between curiosity driven research and national agenda (competitiveness of the country). Therefore, NIST also conduct 'basic research' especially those related to measurement and standards. There are three important criteria when it comes to selection of research topics. First, NIST discusses with the industry to find out their demand. The topic must be in line with NIST's core mission and expertise, and will lead to development of NIST's scientific capabilities. Finally, outcomes of research should benefit several sectors and firms, not only individual ones.

NIST also conducts 'technology scanning' every quarter: following on what technology trends, analyzing them, and categorizing them into what should do now and later on. The exercise is managed by Office of Program Coordination. NIST used to have Economic Study Department as well.

NIST employs about 3,000 scientists, engineers, technicians, and support and administrative personnel (around 50% being scientists and engineers). Several Nobel laureates are working at NIST. Though researchers working at NIST are not tenured, many of them are rather long-term ones, compared to other government research institutes in the US. However, there is no job guarantee. There are also contracted employees attached to individual projects. NIST has 'postdoctoral program' in collaboration with NSF whose aim is to cultivate scientific talents. NIST later recruits some of these post-doctoral researchers participating in the NSF program. Some worked with NIST and left later. So there is a certain degree of mobility especially at level of young researchers. NIST also hosts about 2,700 associates from academia, industry, and other government agencies, who collaborate with NIST staff and access its facilities. As for researchers working in the industry, they can come to work with NIST for a year or so to use NIST's facilities and work with NIST's researchers. Therefore having large national facilities at public research institutes can incentivize collaboration with the industry. Some NIST's researchers left and started new companies, but this practice is not encouraged (though not discouraged). In addition, NIST partners more than 1,300 manufacturing specialists and staff at more than 400 MEP service locations around the country. Their mission is to help local SMEs.

NIST's FY 2014 resources total $850.0 million in direct appropriations, an estimated $47.3 million in service fees, and $107.0 million from other agencies such as Department of Defense and Environmental Protection Agency (EPA). NIST has no aim to generate incomes from industry. Some of its measurement services cannot even cover full cost. Nonetheless, NIST’s two large facilities (Center for Neutron Research and Center for Nanoscale Science and Technology) provide industry, academia and other government agencies access to world-class nanoscale measurement and fabrication methods and technology on the fee-based share-use basis.

NIST has four center of excellences attached to four universities. As one of NIST’s campuses is in Colorado (Boulder), NIST has close relationship with *University of Colorado* in quantum science research. NIST’s main campus in Gaithersburg, Maryland also has research collaboration with *University of Maryland* on more ‘applied’ disciplines such as marine biology. It also has a partnership with the State of Maryland in developing cyber security. Apart from these two universities, NIST also has collaboration with leading universities like *Northwestern University* and *University of Chicago*. Nonetheless, NIST does not have ‘joint appointment’ system with universities. NIST’s researchers are also members of examination committees of postgraduate students in these universities.

NIST has technology transfer program under the concept ‘from lab to market’. Though licensing is not a prominent mode of NIST’s technology transfer, exclusive license can be given to a particular firm. There are some joint appointments with industry, but not many. NIST does not give a lot of grants to industry. Most budget was spent internally. The most prominent one is the MEP program of Department of Commerce. NIST acts as an intermediary building nationwide network of more than 1,200 technical experts, - located in every state - serving as trusted business advisors on transforming U.S. manufacturers to compete globally, support supply chain integration, and provide access to technology for improved productivity. MEP Centers are a diverse network of state, university-based, and non-profit organizations, offering products and services that address the critical needs of their local manufacturers. Additionally centers connect manufacturers with government and trade associations, universities and research laboratories, and act as a host of other public and private resources to help them realize individual goals. NIST's staff who manage the MEP program are required to have good understanding of the industry and different skill set from that of researcher. Interestingly NIST's own laboratories and their intramural researchers are not well connected to MEP. The research activities and MEP were conducted separately.

Another prominent mechanism is Advanced Manufacturing Technology Consortia Program. The idea of supporting individual firms and sectors are considered rather negatively as government is trying to pick a winner. NIST, therefore, is trying to support 'networks' of manufacturers in the form of consortium. A consortium is not desired to help one particular firm or sector. In the process of forming a consortium, NIST will publicly post a call for proposal. Any firm can participate. However in practice, NIST does make sure that a call reaches trusted companies. A partnership in a consortium evolved overtime. NIST does not set very clear-cut targets from beginning. Nonetheless, if the project fails, NIST can terminate it at an early stage. NIST can perform this intermediary role because it is not viewed by the industry as a regulator. Instead, NIST is a scientific partner with convening power.

Output-wise, in a typical year, the agency's scientists and engineers publish about 2,200 professional journal articles and technical reports. NIST also offers around 100 different types of Standard Reference Data. Around 6000 were sold per year and 25 million were downloaded per year. NIST delivers 1,300 Standard Reference Materials (SRMs)—painstakingly characterized and consistently produced materials that are used to check the accuracy of instruments and test procedures. It distributes more than 33,000 SRMs to customers in U.S. industry and around the world. NIST staff performs about 17,000 calibration tests annually, as well as accredit some 800 private and public testing and calibration laboratories.

NIST does not have many patents, as it believe that NIST's output should be publicly available. In the past, some directors did favor patenting, while others did not. So NIST does not emphasize on filing patent. NIST evaluate research performance by looking at a) publication, citation, and actual use of research outputs in comparison with universities and other public research institutes; b) setting up external peer review, and c) longer-term economic study (Dr. Jason Boehm, personal communication, June 2, 2014).

2.3. Commonwealth Scientific and Industrial Research Organisation or CSIRO (Australia)

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is the federal government agency for scientific research in Australia with its headquarters in Canberra and numerous sites around Australia. CSIRO was created as a part of nation building process. Founded in 1916 as the Advisory Council of Science and Industry, it evolved to the Institute of Science and Industry in 1920 and the Council for Scientific and Industrial Research (CSIR) in 1926. CSIR was structured to represent the federal structure of Australian government, and had state-level committees and a central council. CSIR research focused on primary and secondary industries. Early in its existence, it established divisions studying animal health and animal nutrition. It helped Australia establish primary industries like cotton industries. After the Great Depression, the CSIR extended into secondary industries such as manufacturing. CSIRO is continuously evolving. Historically, at times, it was merged with and splinted from other public research institutes.

Under *CSIRO Strategy 2020*, CSIRO's vision is to be *Australia's innovation catalyst*, boosting Australia's innovation performance. Its mission is to create value for customers through innovation that delivers positive impact for Australia. This mission was initiated quite recently around 2014. Before, CSIRO focused more on basic research. The reason behind the shift is that Australia's policy makers and CSIRO's management thought that CSIRO should address the issue of weak linkages between academia and industry. Australia has done quite well in R&D, with GERD/GDP being 2.1%. There was also large investment on infrastructure with little to do with technology development. However, in between there is a 'Valley of Death'. Private venture capital invested less than 0.1 of GDP in technology related businesses. Government initiatives like 'Innovation Invest Fund' which provide matching grant to startups did not lead to self-sustainable results (after the scheme ended, innovation projects stopped). Therefore, it is understood that CSIRO should play a role of a hub or a catalyst in national innovation systems to address the problem of market (and systemic) failures. Also CSIRO became more global oriented as well, as it tried to have more collaboration with foreign partners.

CSIRO operates through three lines of business:

A) Impact science: 14 business units with focus on the biggest challenges facing the nation. They are agriculture, health and biosecurity, Data 61, energy, food and nutrition, land and water, manufacturing, mineral resources, oceans and atmosphere

B) National Facilities and Collections: CSIRO manages infrastructure and biological collections for the benefit of research and industry.

C) CSIRO Services: CSRIO provides commercial, customer-centric products and services for industry, government and the community, including education, publishing, infrastructure technologies, Small and Medium Enterprise engagement and CSIRO Futures.

CSIRO's direction is set by the CSIRO Board and the CSIRO Executive Team. CSIRO Board reports to Minister of Industry and Science. The board members are selected by minister with consultation with the Chairman of the board.

The minister has power to add to the purposes for which CSIRO may carry out scientific research and provide to the CSIRO Board in writing, directions and guidelines with respect to the performance of the functions, or the exercise of the powers, of the Board or of the Organisation. The Minister provides CSIRO with a Statement of Expectations and the Board responds with a Statement of Intent.

The Board meets at least quarterly and comprises a non-executive Chairman, up to eight other non-executive Members and a full-time Chief Executive. All Board members (other than the Chief Executive) are appointed by the Governor-General. The Chief Executive is appointed by the Board with a final approval by the government.

The current chairman of the board, Mr. David Thodey, was the CEO of Telstra from May 2009 to April 2015, and prior to that had a 22-year career with IBM. Other board members except one came from the industry. A few of them have experiences in venture businesses. Even the only one academic on the board, the Provost and Senior Vice-President of Monash University, played a key role in building one of Australia's first biotechnology companies. The current CSIRO's Chief Executive, Dr. Larry Marshall, was Managing Director of Southern Cross Ventures, a venture capital firm based in Silicon Valley, Shanghai and Sydney.

CSIRO has an external advisory committee. Some members are from the industry. They can provide CSIRO a long-term view of what an industry will be. However, the significance of the advisory committee was reduced recently, since a few chief executives did not like to either have them or listen to them.

Historically, before the year 2000, CSIRO had department structure according to discipline like a university. Nonetheless, in 2000, government had an intention to close CSIRO. CSIRO, therefore, had to find something distinct itself from normal universities, which was the multi-disciplinary nature of its research. To highlight this aspect, CSIRO began to have flagships program encompassing several discipline. It aimed to encourage even more research cooperation across disciplines. CSIRO's flagship programs were executed by flagship directors. However, in 2015, flagship programs were scrapped, as it created confusion in terms of management (i.e., researchers had to report to several authorities like flagship directors as well as their own disciplinary laboratories). The objective of having flagship programs was also achieved, as many researchers did work together across disciplines. As a result, the structure changed to business units. Each business unit focuses on individual challenge.

At present (2016), CSIRO has 14 business units. According to CSIRO's executives, CSIRO cannot be specialized like PRIs in the US. This is because CSIRO operates in a small country whose population is only 23 million and its industry is still technologically weak. Nonetheless, a few critiques who were former managers and researchers at CSIRO stipulated that CSIRO should be more focused. Before, CSIRO represented 30% of Australia's GERD. Now it is downed to 4% and universities' research are stronger than before. Therefore, CSIRO as a much smaller player in Australia's NIS, should leave some research areas to universities and become more specialized somehow

In 2014–15, Total revenue of AUS $1,230.8 million (US$ 875 million) included appropriation from government or block grant (60%) and revenue generated from other sources (40%). Specifically, 5.2% came from contracted research, consulting and services to Australian private sector, 6.6% came from overseas and international projects, and 4.9% came from IP royalty and licenses. In total, less than 20% of revenues come from the industry. State governments also provided some funding to CSIRO but the amount was quite small.

CSIRO works with approximately 3000 customers per year. Central agencies of Australian government are the first (most important) customers. It also worked with 500 major Australian companies which is equivalent to 20% of the ASX 200 companies (top 200 listed firms). It worked extensively with Australian SMEs (around 1200 firms). MNCs are important customers, for example, Boeing, GE, Chevron, Lockheed Martin, Petronas, Petrobras, and Bayer.

At 30 June 2015, CSIRO had a total of 5269 staff, a full-time equivalent (FTE) of 4836.

Research staff is around 65% of total staff. Female research staff is around 26% of total research staff. Over 2000 people have Ph.D. degrees and 500 people hold masters. CSIRO recognized that it needs more researchers who can communicate well in other languages, as CSIRO increasingly work with global partners. At present, Chinese researchers are around 300-400.

Average age of staff is 54. Retirement is at 65. Some distinguished researchers continue as CSIRO fellows (no salary, only office space provided). Only old-generation researchers have tenure or long-term contract. Younger generation has fixed-term contract.

Turnover of CSIRO's personnel is as low as 4% annually. Not many CSIRO's researchers went to industry. Most people who left went to university. CSIRO has a history of not taking its people back after they left, though they are valuable human resources. Nonetheless, CSIRO agrees that mobility should be promoted as it is not healthy to have a people staying with the same organization for 30 years. Therefore, CSIRO recently started a 12-month contract which allows its researchers to work in the industry. After coming back, their experiences can be viewed as a plus for their future promotion.

90% of research is done with partners. Only 10% is basic research with no immediate outcomes. This reflects the change in CSIRO's focus from an organization for basic research to an innovation catalyst, as mentioned earlier. Nonetheless, critiques disagree with this change. They contend that CSIRO should maintain its strength in fundamental research if they want to be an innovation catalyst. This is especially true in agriculture areas where basic research is a significant basis for innovation. CSIRO's research should be in the 'Pasteur's Quadrant' that both seek fundamental understanding of scientific problems and, at the same time, seek to eventually beneficial to society. Also, if CSIRO want to keep its role as a principal scientific advisor to the government as today, it needs in-depth understanding of science and their future development. Some observers argued that it was a mistake to pull out from basic research.

Concerning project selection, a mixed approach between bottom-up (curiosity of researchers) and top down (policy direction from executives) was adopted. Each business unit of CSIRO has industry advisory groups who can recommend research topics. Each industrial sector also has industry surveys which are used in the selection processes. If a project requires a lot of budget and high risk involved, it needs an approval from the headquarters.

For each project, impact return on investment has to be evaluated. Nonetheless, CSIRO has to balance between *breath of impacts* and *depth of capabilities*. Some projects were carried out in order to maintain enough capabilities to collaborate with universities.

ICSIRO has 54 sites around the country. Each local branch is supposed to work closely with local firms, governments and universities. Each branch focuses on local challenges. During CSIR period (the predecessor of CSIRO), regional branches were semi-autonomous. As it became CSIRO, it had less autonomy. The organization was consolidated and resources were shared across organization. Now a regional site has autonomy in terms of project initiation to a certain extent. If the budget for a project exceeds a certain amount, it needs to get an approval from the headquarters. Authority of the chiefs of regional branches and business units reduced; however, they are still important in selecting researchers to work in individual projects.

Co-location strategy (CSIRO's research cite, universities and industry co-locate in a certain geographical area) is adopted. In several cases, CSIRO intentionally acquired land to set up its branch adjacent to universities. More recently, CSIRO had an important role in developing five of Australia's global precincts. In CSIRO's view, proximity is still important. A precinct brings together multiple partners in a shared space with a shared culture of collaboration. At the Clayton site, for example, some research laboratories and office spaces are shared between CSIRO and Monash University as two institutions locate next to each other. Many post-doctoral researchers at this site used to study at Monash.

In general, CSIRO has three channels to communicate with the industry.

- CSIRO’s board. At present, majority of board members are from the industry
- CSIRO’s advisory committee
- Each business unit tries to work with concerned industrial associations or farmer groups in the case of rural agriculture sector. Chief of each business unit is also responsible for marketing of the unit’s activities to the industry. Therefore, a capability of the chief is critical

It should be noted that CSIRO used to have a separated firm called ‘CSIRO Tech’ which conducted marketing activities for the whole organization. However, it was not successful. Neither CSIRO’s researchers, nor the industry talked to this firm. In fact, a business unit’s chief has much better understanding of the technology and authority to discuss with the industry, if he or she is a capable person.

The important modes of collaboration are described in detailed as follows:

Contracted/collaborative research is the most important mode in terms of revenue generation. CSIRO is committed to collaborating and partnering with organisations across Australia and around the world in a variety of ways, including strategic alliances, projects and joint ventures. Degree of collaboration varies. Some projects CSIRO contribute more than 50% of total budget. Some are less.

26% of CSIRO’s patent portfolio is commercially licensed. CSIRO’s licensed. Exclusive licensing can be provided. It depends on case by case. In many cases, CSIRO licensed technologies to firms which had had previous collaborative research. There is a strong connection between collaborative research mode and licensing mode. However, in some cases, CSIRO licensed to totally new firms too. Critiques view that CSIRO need to have this kind of flexible approach regarding commercialization of its IPs, as market evolves overtime and this is beyond the control of CSIRO. Most of the licences generating revenue were to Australian companies, with one third international entities. CSIRO is aware that licensing to foreign companies might strengthen competitiveness of foreign companies vis a vis Australian companies even though Australian firms are not qualified to be licensees of CSIRO's patents.

CSIRO engaged Australian government's Cooperative Research Centre (CRC) program aiming to support industry-led collaborations between researchers, industry and the community. Throughout the life of the program, over 200 CRCs have been funded by the Australian Government. CSIRO has participated in 142 CRCs as a member, not as a manager/coordinator of CRCs.

SME Engagement Centre was established to bridge the gap between Australian industry and the research sector, and help companies adopt new ideas and technologies for a competitive advantage. In 2014, approximately 200 SMEs were supported with information, connections and facilitation of research projects that will allow them to develop a competitive advantage. In addition, 52 projects were facilitated between a researcher and SME to work in collaboration on a technical solution to a company challenge or opportunity. In 2007, CSIRO established the *Australian Growth Partnerships (AGP)* program to provide funds to high-potential, technology-receptive SMEs so they can access CSIRO research and development capability and IP. It is designed to be mutually beneficial, assisting SMEs to overcome existing technical issues, while contributing to CSIRO's research programs. As at 30 June 2015, seven SMEs were engaged in the AGP program.

spin-off is less important. So far, more than 150 start-ups have been created. In 2015, 'Acceleration Program' or 'ON Program' was initiated to a) increase the volume, velocity and value of commercial and entrepreneurial ventures involving CSIRO's IP, staff, and assets-partnering with strategic customers, and b) build the innovation and entrepreneurship skills, culture, and capability of CSIRO's staff and teams. The target of this program is breakthrough innovation leading to development of new industries and products. Within the On Program, there are two major activities.

A) *Lean Launch Pad* (or ‘Pre’ Accelerator). This two-week activity allows CSIRO’s researchers working at early-stage research to experience how to explore and validate their idea through interaction with potential customers.

B) *Acceleration*. This is a much more intensive program of12 weeks. This program encourages CSIRO’s researchers to take customer development to the next level of partnership with experienced mentors and specific experts. They will earn how to position their IP in value chain and design business models that lead to long-term sustainable impact. They will learn how to best articulate their value proposition to customers and investors, and have the opportunity to pitch to them at the end of the program. Researchers were allowed to leave CSIRO and work in their start-ups for 2 years with an option that they can go back to CSIRO. However, only when they permanently leave CSIRO, they will be allowed to take equity in the start-ups.

Apart from the above activities, the ON Program also helps universities’ accelerator programs especially those targeting Ph.D. students in sciences and engineering at the later stages of their studies. It also engaged in ‘demand-driven’ accelerator programs by developing solutions for particular firms, for example, Woolworth (a giant Australian retailer), and other firms in mining and banking industries.

In 2015, CSIRO started to have its own VC fund (CSIRO Technology Venture Fund) to invest in its own spin-off firms. The fund is $ 200 million: $ 70 million from federal government, $ 30 million from CSIRO and $ 100 million from the industry. Out of these, 5 million was allocated to Accelerator Program to manage the VC fund.

CSIRO undertook various collaborations with universities across Australia to conduct research projects, co-author research publications, undertake joint supervision of students and/ or support adjunct appointments. CSIRO’ researchers are allowed to spend 20% of their time at universities under joint appointment arrangement. Most researchers have joint appointment which usually last for 3-5 years. Nonetheless, joint appointments do not work so well, because of different orientation between universities and CSIRO. The latter is more outcome-oriented.

CSIRO worked with partners (universities, government research institutes, and companies) in more than 80 countries around the world. Major partners are USA, China, Japan, and Germany. In terms of time spent, CSIRO equally works with USA and China. However, working with China generated much more income. CSIRO established its first offshore legal entity, CSIRO Chile Research Foundation to deliver solutions to the mining, equipment and services sectors. Chilean government heavily finances this operation.

There are 9 key performance indicators (without any ranking)

1. Impact return on investment
2. Customer satisfaction
3. Active licenses
4. External revenue (IP, industry and international)
5. Collaboration (internal and external)
6. People: Diversity and inclusion
7. People: engagement and innovation culture
8. People: health and safety
9. Investment in future science and technology

These KPIs were used for evaluating business units and reporting to the board and government. Before CSIRO used different indicators, this created confusion. Interestingly, publication is no longer a KPI of CSIRO due to the abovementioned shift in CSIRO’s strategy.

In 1985, government set 30% target of external funding for CSIRO. It had a positive impact as it forced CSIRO's researchers to go out to the industry. In early 2000s, government reviewed that this target was achieved. So the fixed target was dropped. In reality, most external revenues came from central and regional governments, not from the industry. There is a counter argument that the industry alone should not decide on research priorities of CSIRO. Even if the target had achieved, industry would have paid only 30% of the total budget, while taxpayers still paid 70%. Also these critiques argue that by doing so, CSIRO's research would move from 'Pasteur's Quadrant' to 'Edison's Quadrant', which is not desirable.

Regarding ownership of IP generated from collaborative research. CSIRO needs not to own IP. In the view of CSIRO, owners should be the best party who can commercialize IP. In term of benefit sharing, CSIRO should get a fair share. Within CSIRO, officially, no revenues from commercialization of IP are shared by individual researchers. Instead participating researchers may get pay rise and awards.

Mixed evaluation approach between quantitative and quality ones was implemented. The qualitative approach like case studies was useful in terms of producing narratives for politicians and the public to understand what CSIRO have achieved. In 2015, 10 case studies on impact on society of CSIRO's research were carried out.

Every 4-5 years, business units of CSIRO were evaluated by the third party. The third party comprises people from academia and industry, who did not have any conflict of interest. Results of the evaluation led to scrapping of a few flagship programs (other reasons like changing environment also being important) and realignment of research focuses.

2.4National Institute of Advanced Industrial Science and Technology or AIST(Japan)

Although some of the laboratories constituting AIST were established more than 100 years ago, the direct precursor of AIST—the Industrial Technology Agency (ITA)—was established in 1948. Following a succession of restructuring as well as a name change, a large laboratory was built in Tsukuba in 1980, which is 50 km outside Tokyo. At that time, it was a science city in the making. In 2001, it was incorporated as an independent administrative agency upon the integration of the 15 laboratories under the auspices of the Ministry of Economy, Trade and Industry (METI). Today, it has its main laboratory in Tsukuba.

AIST has three missions. First, research and development on basic, platform technologies such as measurement standards and geological survey, and other basic technologies needed as technological infrastructure. Second, research that is long term and high risk and should be carried out by government responsibility such as energy and environment. Third, research that promotes innovation by wide-ranging search and fusion of many research fields in order to promote international competitiveness and creation of new industry (Sawai, 2011). It covers six fields; environment and energy (of which 24% researchers are engaged in 2014), life-science and biotechnology (18%), information technology and electronics(17%), nanotechnology, materials and manufacturing(15%), metrology and measurement science(16%), and geological survey and applied geoscience(10%).

The revenue of AIST in 2013 was 94.0 billion yen (or around 940 million US$), of which 59.1 billion yen is block grant from the government, 11.3 billion yen (17%) is also from government for facilities and equipment and 23.5 billion yen from other sources. Among revenue from other sources, fee for collaborate research with industry was 3.0 billion yen, and fee contract research from industry was 810million yen. Majority of "other sources" is fee for contract research for government ministries. AIST employs 2921 people as of July 1, 2013. Among them, 2255 were researchers, of which 1948 were are tenured. In addition, it accepts about 4500 visiting researchers through the industry/academia/government partnership program (1,700 from industry, 2,000 from academia, and 800 from other PRIs) in 2012.

President of AIST comes from academia or industry, and among eleven vice presidents, eight of them are promoted from within AIST, two from Ministry of Economy, Trade and Industry to which AIST reports, and one from industry. Several METI officials are working at AIST at senior management positions.

There are three types of research units within AIST. The first type of research unit is called research institutes. Their aim is to keep continuity of operation to implement mid- and long-term strategies of AIST. Research institutes are also expected to maintain technical potential of AIST and to develop new fields of technology. Currently, there are 22 research institutes. The second type is called research centers. They are limited-term (typically 7 years) organizations with clear goals. Research resources of AIST, such as budget and personnel, are strategically distributed, and research centers have priority to the resources. Twenty of them exist today. The third type is called research laboratories. They are rather small units of limited terms. The purposes of research laboratories are to promote specific research projects, especially those of cross-fields. Some research laboratories also aim to meet immediate governmental needs. There are none of them at this moment.

In addition, there are eight regional laboratories. Their emphasis used to be helping local industries. Now they were reoriented towards research institutes with specific research area such as bio manufacturing (Hokkaido Center), advanced material processing (Chubu Center) and health engineering (Shikoku Center), reflecting the strength of industry in each region. Its role as regional centers to help industries in each region in general is carried with the collaboration with public research centers established by local governments.

AIST and its predecessor ITA have a long history of contribution in planning, coordinating, and promoting most of the large-scale national R&D projects. They are in most cases organized as Research Associations which are one of the important vehicles of collaborative research among firms, universities and public research institutes.[3] Most Research Associations in Japan are created by the METI (formerly MITI) initiative to

[3] As for the Research Association, see Goto (1997)

coordinate industrial participation in a specific METI large-scale project. In 2014, 63 Research Associations exist, and AIST is involved in 20 of them.[4] In this sense, AIST is an integral part of Japan's industrial policy.

AIST has ties with 28 universities through agreements to develop various technologies, and agreement on graduate course under which AIST send their researchers to graduate schools while taking graduate students at its laboratories.

As mentioned earlier, AIST's main mission is to explore next-generation key technologies through advanced research. Like other public research institutes, it uses the metaphor of a bridge connecting basic research with development, or connecting university with industry. A well-known case where AIST (one of its laboratory in Osaka) played a pivotal role in this manner is the development of carbon fibre. An AIST researcher, Dr. Sindo, discovered the basic principle of manufacturing process of polyacrylonitrile carbon fiber, and its patent was licenced to Toray, a Japanese textile and chemical company. With technical assistance from AIST, Toray successfully developed commercially viable production process. It is used from tennis rackets and fishing rods to aircraft bodies today. Toray is the largest manufacturer, controlling about 40% market share world-wide.

This is a kind of a case with which AIST researchers want to define its role in Japan's innovation system, i.e., when a material with interesting characteristics is known and produced in a laboratory, but firms are reluctant to invest in developing commercially viable manufacturing process as it will take long time. This seems to be the case in recent years. AIST can take up these projects and work with a firm or firms interested in them. During this process, it is often the case that basic scientific research may be required, and they can be published in professional academic journals. This is why AIST has "science" in its name. Once they are successful, technology would be handed over to industry, with technological assistance from AIST. Today, with the intensified competition globally, firms

[4] The law on RA was amended and AIST became able to be a member of RA. But even before the amendment, AIST was involved in RAs in many ways.

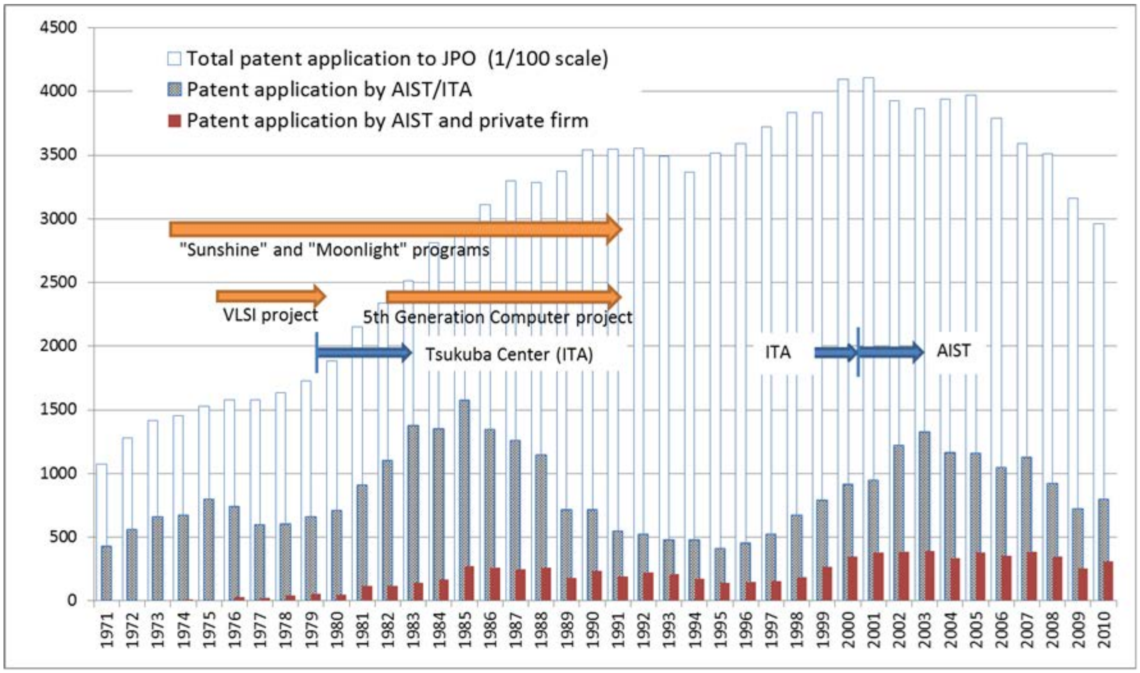
are finding it increasing difficult to conduct long term research. Therefore, according to AIST, this role of AIST in Japan's innovation system is increasingly important.

This argument is based on linear model, where innovation process is considered to start from basic research, then followed by applied research, and finally, development of new process or product. This view is, of course, not totally wrong. There are cases especially in science-based industries where actual innovation seemed to have occurred in this manner. However, it is also known that many innovations started from problem solving process of firms.

During the 1980s in Japan, the discourse on technology policy was centred around the need for more basic, fundamental research. There were two reasons. First, there was a feeling that Japan reached world frontier of technology in many industries. In fact, Japan became the largest producer of semiconductor, automobile, and iron and steel in the 1980s. Japan borrowed most of the important technology it could borrow from the West, and now on, Japan had to invent from the scratch, and basic research was important to do so, as the argument went. The second reason was the trade conflict with the US. The US criticised Japan for using the US technology without contributing to basic knowledge, the world public good. With these backgrounds, PRIs emphasized basic research in this period, which was of course welcomed by researchers of PRIs.[5]

In the latter half of the 1990s, the direction changed again. With the prolonged economic slump, more "practical" research that could contribute to creation of new industry and jobs was emphasized. More contract and joint research with the industry is encouraged. The changing number of patents applied by AIST, shown in Figure 1, may reflect this changing emphasis, although it was also affected by other factors such as the changes in patent system, such as the adoption of complete multiple claim system in 1988.

[5] In this period, number of patents by PRIs decreased. Researchers at PRIs were conducting kind of research which could be published in leading scientific journals like Nature and Science. See details in Suzuki, Tsukada, and Goto (2013).



Source: Suzuki, Tsukada, and Goto (2013)

Figure1. Trends in AIST's patent applications

2.5 Industrial Technology Research Institute (Taiwan)

Industrial Technology Research Institute (ITRI) is a non-profit PRI responsible to and partially supervised by the Ministry of Economic Affair (MOEA), a key economic ministry. It was an amalgamation of three MOEA's laboratories in 1973. It is located in Hsinchu Science-Based Industrial Park, where there are many foreign transnational corporations and Taiwanese firms, and two national universities (National Hsing Hua and National Chao Tung) which provide high-quality graduates and co-operative research.

ITRI's mission is very clear. It spearheads new industries and upgrades existing ones. ITRI positions itself as a 'bridge' or a 'partner' for Taiwanese firms by a) leading in national R&D projects, b) facilitating technology diffusion and spin-off, and c) fostering talent flow and encouraging entrepreneurship. At present (2014), ITRI has six research laboratories: biomedical technology and device, green energy and environment, material and chemical, mechanical and systems, information and communications, electronics and optoelectronics. There are another six focused centres which can be transformed into full laboratories once technologies are confirmed. As of February 2014, ITRI had 5,799 (1,383 Ph.D. and 3,751 master, 1,265 bachelor graduates). ITRI's management has extensive industrial experience. Several board directors and executives have worked several years in the private sector before joining ITRI. Some like former ITRI's president, Dr. Morris Chang, worked for world-class firms abroad and still maintain close links. ITRI and Hshinchu Park also attracted back US-trained Taiwanese researchers, engineers and managers (Hobday, 1996). These people were instrumental in establishing ITRI and assisting the industry.

From earlier stage of development, ITRI set up an explicit target of acquiring half of its annual income from the industry. In reality, 65% of revenues came from public sector, of which those from MOEA (especially Technology Development Program: TDP) and another 35% came from the industry. This ratio has not changed much overtime. It is noteworthy that there is no *block* grant from government. All budgets from the government are project-based and competitive.

ITRI's support to industry has co-evolved with development of Taiwan's national innovation system and technological capability level of firms. During the catch-up period of 1970s to the early 1990s, Taiwanese firms were latecomers catching up with innovative forerunners in advanced countries. They had to rely on technologies generated elsewhere. ITRI, therefore, focused on diffusing leading foreign technologies, especially in manufacturing, and helping firms develop their 'absorptive capacity' to understand, assimilate and upgrade those technologies. Since the late 1990s, when Taiwanese firms had mastered design and engineering capabilities, leading firms started to carry out in-house R&D and changed their status from 'imitator' to 'innovator'. As a result, the focus of ITRI changed to helping local firms build up R&D capabilities and develop leading-edge products. Since the 2000s, ITRI aggressively conducts research and develops countless next-generation technologies, including WIMAX wireless broadband, solar cells, RFID, light electric vehicles, flexible displays, 3-D ICs and telecare technologies. It is also active in life science, biomedical devices and nano technology (ITRI, 2012).

The technology transfer mechanisms of ITRI have also evolved with the changing role of ITRI (see Table 2). During the earlier phase, ITRI spun-off several units which later became global leader in semiconductor industry like TSMC and UMC. R&D consortium were also used to overcome network failures among local firms in the same industry, as ITRI acted as an intermediary and a resource provider to diffuse and upgrade existing technologies and building trust among participating firms . They have been around 30-80 small and large consortium set up by ITRI so far, depending on definition. Some consortia were tightly knitted, as members including ITRI jointly decided on technologies and strategies. Some were loose and informal, which ITRI only had roles in providing market and technology intelligence. Nonetheless, some organically developed from informal and loose to formal and tightly knitted ones. A remarkable success is the case of the Notebook PC. ITRI developed draft specifications for a “common machine architecture” and invited Taiwan Electrical Appliance Manufacturers’ Association (TEAMA) to be the joint coordinator. Later no fewer than 46 companies joined the consortium. A prototype was then developed and translated into a series of standardized components that could be mass produced by Taiwanese manufacturers. ITRI followed up by providing extensive training to member firms. Many of the ITRI engineers moved across to member firms, which was another form of diffusion of technological capability (Mathews, 2002).

At present, it is noteworthy that commercialization activities of ITRI are carried out at two levels. Most activities are done at each laboratory center which have around 30-40 non-research staff responsible for commercialization. The centralized unit, Commercialization Industry Service Center, only concentrates on multi-disciplinary and strategic projects. This center adopted four commercialization models: key account management, industrial services, venture business, and incubation business.

- Key Account Management is what ITRI offers technological solutions through a single contact window for large company customers like TSMC which prefer to work with ITRI on one-to-one basis.
- ITRI provided industrial services to SMEs under financial support from government programs, especially Taiwan's Small Business Innovation Research (SBIR). ITRI sometimes taught SMEs how to apply for government supporting programs.
- The center's venture business has two strategies: spin off and spin in. ITRI's research team with strong own intellectual property rights set up a new company. ITRI's own venture subsidiary can take a minority share in a spin-off to create confidence among private investors. Alternatively, ITRI's team can set up a new business unit inside a large existing firm.
- ITRI offered the first incubation service in Taiwan in 1996. Incubates must be less than 18 months old and have less than 80 million NTD of initial registered capital. Normally incubatees stayed with ITRI for seven years. So far, 180 firms have been incubated, 70 of them could move to the science park and 18 reached initial public offering (IPO) stage.

Table 2: Evolution of Roles and Supporting Mechanisms of ITRI

Period	Level of Technological Capabilities of Local Firms	Roles of ITRI	Supporting Instruments
1970s - early 1980s	Only basic operation capabilities but not design and engineering. Insufficient absorptive capacity.	Acquiring foreign technology through licensing in. Then carrying out R&D to understand, assimilate and adapt such technology. Then setting up new companies through spinning off from ITRI	Spinning-off to create start-ups such as United Microelectronics Corporation (UMC) and Taiwan Semiconductor Manufacturing Company (TSMC), which later became world-class companies
1980s - early 1990s	Gaining design and engineering capabilities.	Acting as an intermediary to set up R&D consortium with local companies. The consortium conducted joint research leading to prototypes which were subsequently developed further to be commercial products by each	R&D consortium such as R&D consortia of notebook producers and R&D consortia of High Definition TV (HDTV) producers

		participating firms.	
late 1990s-present	Having R&D capabilities. Emerging of techno-preneurs interested in setting up new technology-based firms.	Strengthening R&D capability and R&D management of firms. Encouraging start-ups.	'Open Lab' allowing SMEs to use ITRI's R&D lab incubator and venture supports to nurture start-ups spin off and spin in

Source: Intarakumnerd (2011)

Remarkably, informal mechanism of human resource mobility played very crucial roles in transferring significant knowledge to industry and establishing foundation for more formal collaboration between ITRI and firms. Less than half of ITRI's personnel kept working at ITRI until they retired. In the past 30 years, 22,000 ITRI employees have left ITRI and taken their talents into private industry, especially firms in the surrounding Hshihchu Science Park. Some of them returned to work at ITRI in more senior positions. At present, 5,000 former ITRI's employees are working for private companies in Hsinchu Park itself. They help to establish both formal and informal knowledge-sharing networks between companies and ITRI.

After Taiwan became industrialized and high-income economy, ITRI has not shifted to basic research at all. Both ITRI itself and MOEA think ITRI should still carrying out the same missions as before, that is, spearheading new industries and upgrading existing ones. Though many Taiwanese firms in some industries, especially ICT became large and global players, ITRI is always focus on supporting SMEs (accounted around 75% of ITRI's clients). It can also conduct research on these industries' next-generation and prospective competitive/disruptive technologies which may be perceived as too risky or out of scope by existing firms. ITRI is now receiving contracted research to work on this type of technologies from both government and large firms like TSMC. In addition, ITRI can support creation of start-ups in new industries like biotechnology, biomedical devices, service industries and so forth. Analysis of ITRI's present revenues confirms this division of labour inside ITRI. One half of revenues come from projects supporting short- and medium-term demands to solve today's problems of the industry. The other half come from either long-term research to develop core technologies for the future, or exploratory and risky projects aiming to develop new industries.

Nonetheless, the difference from the past is on the strategy to achieve the goal of supporting industry. In the past, ITRI's main strategies were to localize and diffuse foreign technologies. At present, ITRI has enough capabilities to develop its own technologies in collaboration with strategic partners like local and foreign firms and universities which can help in terms of conducting joint long-term and stable research.

Interestingly, a patent ownership analysis by Shiu et al (2013) illustrate that ITRI after the 2000s, collaborated with more diversified types of actors, especially firms and industrial associations participated in ITRI-initiated consortium. ITRI also collaborated more with universities, especially those two located in Hshinchu (National Tsing Hua University and National Chiao Tung University). Universities are both research collaborators and competitors for government's projects.

In parallel, ITRI's pursue internationalization strategy to leverage strength other countries' national innovation system. It has offices in the United States, Japan, Germany, Russia and Netherlands. In the United States, it has long-term collaborative arrangements with MIT, Carnegie Mellon University, the University of California at Berkeley and Stanford University (ITRI, 2012).

Table 1 summarizes characteristics of the case studied PRIs, especially their evolution of their roles and mechanisms in supporting the industry.

Table 3. Characteristics of Selected Research Technology Organizations in Industrialized Economies

	Birth Year	**Revenues (US$)**	**Number of employees**	**Funding Sources (government: industry/competitive sources)**	**Evolution strategies**	**Key mode of interaction with industry**
Fraunhofer (Germany)	1949	2476 million (FY2012)	22,000	1/3: 2/3	Basically satisfying present needs of industry. Recently small fund allocated longer-term R&D. Internationalization.	Contract research and people mobility. Bridging industry with university.
CSIRO (Australia)	1916	875 million (FY2014)	5,200	60%:40%	Moving from a basic research organization to an innovation catalyst.	Contract research and licensing.
AIST (Japan)	1948	940 million (FY2013)	2,900	75%:25%	Long-term research to create new industries. Then moved to more basic research. Lately swung back to more practical research	Licensing, contract research, research consortium
NIST (US)	1901	1,004 million (FY 2014)	3,000	Most from government (no aim to generate incomes from industry)	Focusing on basic research' on measurement and standards with *unrelated* activities to support industry especially SMEs	Provision of large scientific facilities. Acting as an intermediary by facilitating networks

						of local expert and R&D consortium to help SMEs.
ITRI (Taiwan)	1973	631 million (FY2012)	5,800	65% from *competitive* government grants:35% from the industry	Co-evolution with NIS. Always focusing SMEs. Recently moved to research on next-generation and prospective competitive/disruptive technologies too risky or out of scope by existing firms.	Contract research, people mobility, spin off, R&D consortium, and later, incubating, licensing, spin in, and venture creation

Source: Author's interviews and own analysis

3. Discussion on Roles and Success Factors of PRIs

It is quite obvious that all five PRIs mainly focus on supporting the industry, though there are different in mode of interaction. Contracted research is important for Fraunhofer, CSIRO and ITRI but not for NIST and AIST which emphasises more on basic intramural research to serve industry demand. Informal technology transfer through researcher mobility with the industry is very critical for Fraunhofer and ITRI, whereas mobility of researchers at NIST concentrate on early-career postdoctoral researchers who predominantly left for universities. Interestingly, intermediary roles of all five institutes are increasingly significant. All have been trying to be nodes facilitating network building to help firms in various forms especially R&D consortium and geographical clusters linking local firms with local experts and local universities. Particularly, Fraunhofer institutes are integral part of local innovation system of Germany alongside with universities and industry research labs. ITRI is the knowledge hub of Hshinchu Science-based Industrial Park, co-located with universities and industry labs. CSIRO also co-locates their research sites with universities around Australia.

From the case studies, we want to discuss some key factors influencing success and failure of PRIs.

A) Funding

At least substantial part of the funding should come from industry. Fraunhofer receives basic government's fund equivalent to only 1/3 of total budget of an R&D project. Another 2/3 must come from industry, government competitive grants or other sources. Likewise in the case of ITRI, 65% of revenues came from government competitive grants and another 35% came from the industry. This practice makes both institutes quite industrial relevant. As a result, one third rule of funding (1/3 institutional funding vs. 1/3 competitive funding vs. 1/3 funding from industry) should be encouraged for PRIs whose main mission is to increase competitiveness of today's industry. Nonetheless, this rule is not universally applicable. Most NIST's budget comes directly from government. This is, to a considerable extent, because a large proportion of NIST's research is basic research to lay out *technology infrastructure*, i.e., measurement and standards, for the *future* of American industry. As a result, current industry's demand for such research may not be so high. AIST also depends heavily on government block grant, although it tries to increase contract research from industry. CSIRO made a significant attempt to change from a basic research organization to an innovation catalyst. They even set a 30% target for an external funding as early as 1985. Nonetheless, most of their external fund came from government agencies. The industry contribution alone is less than 20%.

B) Researchers

The pace of technical change at the frontier is very rapid. PRIs in industrialized countries have to maintain research capability when research subjects changes over time. The question is how to achieve this objective. On the one hand, PRIs needs to continuously upgrade research capability by hiring new researchers having new capabilities and interests. On the other hand, it is necessary to maintain core researchers to ensure continuity of research and utilisation of institutionalised organisational knowledge. Therefore there is a debate between the virtues of tenured or permanent researchers versus those of limited-term contracted researchers. While turnover and mobility of researchers at ITRI and Fraunhofer is quite high, most of researchers (except postdoctoral ones) at NIST and AIST are permanent staff. PRIs have to strike a balance between the two objectives. This balance depends on mission of PRIs and the pace of change in technologies and industrial sectors in which PRIs are specialised.

C) Setting research agenda

There are several issues concerning setting PRIs' research agenda. Who should have more say in setting research agenda? Should it be an initiative from industry or a suggestion from PRI researchers themselves? Of course, the answer should be a combination of both. Empirically, all five PRIs demonstrate that both sides are important, though with difference weight. As Fraunhofer and ITRI rely more on contracted research and competitive funds, they have to pay a lot of attention to customer demand, while main funding of NIST and AIST come directly from government. CSIRO is in between as most of its fund came from government but it also tries to be an innovation catalyst.

How to select the best projects and areas to help industries? For Fraunhofer, the most important criterion for starting a project is it must secure 2/3 of its budget from outside. In other words, any new project should be good enough to be largely funded by external financial sources. Therefore research is predominantly applied in its nature. In more recent years, its interest in basic research increased, but it is still marginal. ITRI mostly conducts applied research to serve customer needs. CSIRO only spent 10% of their budget on basic research. For NIST, as provider of technology infrastructure for industry, a large proportion of research can be classified as basic research. AIST focuses on research that can bridge basic and development or those of university and industry. Interestingly all the five PRIs have also been engaging in research on industries' next-generation and prospectively disruptive technologies which may be perceived as too risky or out of scope by existing firms. In a way, some parts of their research is in the 'Pasteur Quadrant', bridging the gap between "basic" and "applied" research by both seeking fundamental understanding of scientific problems, and, at the same time, seeking to be eventually beneficial to society (Stokes, 1997). It should be noted that even in the case of Pasteur, basic research was started to respond to acutely felt need to help patients of small pox, and not the other way around[6].

Also there is an issue regarding specificity of research. Would it be alright to strategically conduct research supporting one particular company to cross "valley of death"? Alternatively, do PRIs have to choose the subjects wide enough, involving many companies and industries, so that they are considered fair and not distorting market

[6] In the context of industrialized countries where firms have relatively high technological capabilities, one interesting question that emerges from this discussion is which is more effective to help industry, providing research funding directly to industry to conduct more long term research vs through PRIs. To bridge the gap between basic research and development, government can provide subsidy to firms. Why give money to PRIs to do that? Firms should know better which technology is promising. And firms may prefer to get money and do it themselves rather than obtaining technology from, or working with PRIs.

mechanism?[7] Again, in the case of ITRI, CSIRO and Fraunhofer, they can have contracted research with a company on one-to-one basis. ITRI conducted R&D consortium focusing on developing one particular product like notebook with a group of firms. AIST can also take an active part in research association with specific purposes. NIST, on the contrary, expects that outcomes of research should benefit several sectors and firms, not only individual ones. Therefore, mission of PRIs, nature (basic vs. applied) and specificity of their research and how to select research projects are intertwined.

D) Performance evaluation

Performance of PRIs is a big concern among policy makers and the public at large. Interestingly, NIST and Fraunhofer do not consider neither patent nor publication as a key performance indicator. Only ITRI seriously monitors its performance in terms of number of patents, number of technology transfer, number of spin-off companies, and number of training costs and provided technical services. AIST monitors these numerical indices but it has emphasized more on economic outcomes recently, even though it is not easy to formulate and track those outcomes, such as employment. CSIRO took out publication from its indicators and now pay much more attention to return to investment, customer satisfaction and external incomes. Beyond numerical data of outputs, longer-term impact assessments were conducted for the NIST, Fraunhofer, CSIRO and ITRI either by themselves or third-party evaluators, or both. Nonetheless, these are difficult exercises. The bottom line for PRIs whose mission is to help the industry is whether a large part of their incomes come from the industry, and, to lesser extent competitive grants. If so, it means that they serve the industry well enough.

E) Geography matters

Distance matters in a major way for PRIs to function effectively as knowledge hubs of national or regional innovation system. It matters in a different way. Taiwan, spin-off companies locate around ITRI campus in Hsinchu Science-based Industrial Park, allowing

[7] It may be more difficult now to provide sector-specific subsidies, even on R&D, under the rules of WTO

them to maintain close contacts, receiving technological advice and so forth. Large volume and high frequency of mobility of researchers between ITRI and the industry underpinning knowledge transfer and innovation was also possible because of this geographical proximity. In case of Germany, as discussed earlier, Fraunhofer institutes locate next to universities and/or research facilities of companies in many regions and forming integrated research compounds in those regions. This ‘co-location’ concept makes it possible for three parties i.e., Fraunhofer, university and industry work closely, benefitting all three. University professors can double as directors of Fraunhofer, students can study at university and at the same time work at Fraunhofer and familiarize themselves with industry research. Firms can utilize Fraunhofer’s and universities knowledge with their everyday face to face contact. There are quite a few research on the impact of distance on knowledge transfer, and research collaboration.[8] CSIRO also co-locate their regional branches next to universities in order to share facilities, conduct collaborative research and supervise Ph.D. and post-doctoral researchers.

F) Governance

In all five institutes, there were people from the industry who later became members of boards of directors, boards of executives, and boards of important programs. In the case of ITRI, CSIRO and AIST, at some points, the presidents or chief executives even came from the industry. This signifies that inputs from the industry on management and governance of research institutes are necessary in order to shape the overall strategic direction of PRIs and directions of important research program to be more industrial relevant. Of course, this practice needs to be balanced by appointing distinguished researchers from academia and promotion of internal staff.

What is also important is relationship with economic ministries, as these research institutes focus on helping the industry. NIST is under the Department of Commerce, ITRI is funded

[8] See, for instance, Breschi and Malerba (2001), Asheim and Gertler (2005)

and supervised by Ministry of Economic Affairs and CSIRO is under Minister of Industry and Science.

External evaluation by third party is a common practice. Again, the most important key performance indicator for Fraunholfer and ITRI is income and induced investment from the industry, not number of granted patents. Recently AIST and CSIRO started to pay more attention to final economic outcomes like employment and impact on investment respectively.

4. Conclusion

We acknowledge that each country's national innovation systems are different in terms of characteristics of actors, their interaction and underlying institutions. It would be difficult and inadvisable to have wholesale prescription on how to run PRIs successfully. Nonetheless, from our case studies of five leading PRIs with specific mission of supporting industry, we can draw the following concluding remarks and policy implications for other public research institutes in developed countries.

Firstly, all five PRIs have their success stories. ITRI was successful in incubating Taiwan's electronics industry during the catching-up phase. AIST conducts long term research. Some of their research outputs like carbon fiber, which significantly contributed to creating of new industries. Fraunhofer was widely credited for their support to German industry through contract research. NIST is located in the US where PRIs was not encouraged to conduct research that directly supports industry. Hence it focused on doing excellent research to produce 'public goods' like setting industrial standards. CSIRO made important contribution to mining, food and agriculture industries in Australia. These success stories illustrate that, *to be successful, roles of PRIs should fit the nature and level of development of national innovation systems where they are operating.*

Secondly, for PRIs focusing on long-term research and creating ‘public goods’ like standards, direct finance (block grants) from government and rather permanent employment system is important to ensure continuity and addressing market failures. However, for contribution from the industry, competitive grants and mobility of researchers (especially with the industry) is important for the PRIs which have to the main mission to create new industries and upgrade the existing ones. Having said that, an industrialized country with high per capita income and living standards can still be at catch-up stage in certain industrial sectors. Also even in leading industries, there are still firms, especially SMEs, lacking behind others. Therefore, roles of PRIs in helping these firms in acquiring, assimilating and upgrading their capabilities are still critically important. It is more a matter of *weighted importance, specialization and division of labour* within PRIs. For instance, one half of ITRI’s budget is for supporting short- and medium-term demands to solve today’s problems of the industry, especially SMEs. The other half is for either long-term research to develop core technologies for the future, or exploratory and risky projects aiming to develop new industries. In this process, PRIs can work with large companies.

Thirdly, mission of PRIs, nature (basic vs. applied) and specificity of their research and how to select research projects are intertwined. Even PRIs whose main task is to serve the industry can have different detailed missions. For those aiming for creating broad technology infrastructure for industry like NIST, a large part of their research is basic one, not targeting particular firm or sector. The quality of this type research at NIST is maintained at the very high level as exemplified by the number of its Nobel laureates. Internal technology capabilities, as well as industry’s demand, determine how they select research topics. On the other hand, customer-driven PRIs would conduct more applied research which can be strategically support individual firms and sectors. This type of PRIs also engages in basic research to a certain extent to maintain their research capability and to ensure that outcomes of basic research can be useful for the industry in the future. Another type of the definition of the domain of PRI is to conduct research which lies between early discovery and industrial production. This is what AIST of Japan try to position itself as a bridge between these two stages, leading to creation of new products or even industries. In this case, there need to be a governance system to ensure that its research can somehow contribute to the industry in the future. Therefore it is important to choose relevant projects with close contacts and consultations with industry. Also, mobility of researchers is important to maintain research capability in new fields and industrial relevance. Funding from industry, at least certain percentage may useful to make research relevant to industry, as the case of Fraunhofer shows. The case of CSIRO trying to move from basic research to innovation activities, while still relying heavily on block grant from the government demonstrates the difficulties in changing PRI's mission.

Fourthly, as countries are more or less at technological frontier, it is observed that relationship between PRIs and firms and non-firm actors, especially, universities became more intense, open, horizontal and longer term. It is critical for PRIs to adopt more open attitude and develop capabilities to effectively work with other actors in this kind of environment. At the same time, it is increasingly important to work with actors beyond national borders. These studied PRIs pursued internationalization strategies in order to collaborate with actors in both advanced and catching-up countries in production of new knowledge and exploiting their existing one.

Fifthly, as technological options become riskier and more uncertain, and the nature of innovation is more open, 'intermediary' roles of PRIs are even more important. As illustrated by experiences of all five case studies, PRIs can help to mitigate *network failures* among firms and between firms and non-firm actors through mechanisms like R&D consortium and manufacturing extension programs incorporating local SMEs, experts and universities in different geographical areas.

Sixthly, regarding mode of interaction with industry, unlike conventional wisdom, patent-based licensing is much less important than contract research. Remarkably, an informal mode like *mobility of researcher*s, *engineers and managers* is not only effective way of promoting knowledge exchange but also in mitigating network failures and establishing and strengthening relationship based on trust and longer-term benefits between PRIs and industry. This is quite obvious in the cases of Fraunhofer and ITRI. This has a serious implication on PRIs' employment policy. Of course, PRIs need to have a certain number of tenured staff to ensure continuity and institutionalise organizational knowledge. However, PRIs should not only retain existing talents but pressure and incentivize them to leave and work for industry, at the same time, attract new talents from industry and somewhere else and train them.

Seventhly, geographical operation matters and it is linked to the issue of PRIs being knowledge hubs of local and national innovation system. As each geographical area in a country can have different industry specialization, the localization strategy of public research institutes is necessary. Importantly, the strategy of co-locating public laboratories with local/regional universities and laboratories of firms as in the cases of Fraunhofer, ITRI, and, to lesser extent, CSIRO, is a critical factor for close collaboration among the three parties, since it enables face to face-to-face daily interaction, joint appointment of staff, and mobility of researchers and students.

Eighthly, roles of PRIs in educating and training human resources are quite critical. As PRIs are closer to the industry, compared to universities, the role of PRIs in training young *industrial* researchers and engineers is highlighted. Collaboration between PRIs, university, and industry in research and training of young researchers and engineers, being carried simultaneously by Fraunhofer and CSIRO can be good examples for other PRIs.

Ninthly, as income and induced investment from the industry is the most important key performance indicators of PRIs, PRIs' strategy and government policy on PRIs' incomes are very crucial. From case studies, PRIs would be forced and incentivized to have closer relationship with the industry, if clear and progressive milestones to earn a significant proportion of their incomes from the industry and/or competitive sources of fund were imposed on their laboratories and networked institutes as key performance indicators. However, government subsidies for basic overhead costs, especially during economic downturn, are necessary to ensure that PRIs can continue performing risky and uncertain research leading to creation of new products and/or industrial sectors without falling victim of too much short-term and customer oriented research. Therefore, one third rule of funding (1/3 institutional funding vs. 1/3 competitive funding vs. 1/3 funding from industry) should be encouraged.

Last but not least, governance is important to make sure that PRIs are relevant to industry and at the same time, maintain research standards. ITRI was successful during when Taiwan was in the catching up stage, however, today, it finds itself in much more difficult position as Taiwanese firms are closer to the technological frontier. In order to maintain relevancy, industry involvement in management of PRIs is necessary. It is even much more important for PRIs operating in the countries where firms being technological leaders. Insiders alone should not dominate the decision making. Furthermore, government should not micro manage PRIs. It should provide only a broad direction and evaluate PRIs based on short-term indicators like funding from the industry and long-term indicators like contribution on creating new industries and products.

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