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Benchmarking Research and Technology Organizations (RTOs): A Comparative Analysis

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ACCELERATING INNOVATION in BRAZIL

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1 Introduction

This paper has been prepared in the context of the project *Accelerating Innovation in Brazil*, based at the MIT Industrial Performance Center. This applied research project, sponsored by SENAI, Brazil's National Service for Industrial Training, has a dual purpose. First, to advance understanding of Brazil's national and regional innovation ecosystems along three particular dimensions: (1) the national and regional institutional contexts for innovation, (2) the role of particular institutions and organizations, such as government, universities, and research institutes in the innovation system and (3) the participation of Brazilian industry in global value chains.

Second, in the tradition of past research done at the MIT Industrial Performance Center, it purpose is to inform practice and decision-making. In this case, it aims to inform strategy and implementation for the creation of a national network of applied research organizations, the SENAI Innovation Institutes, hereafter referred to as "ISIs" for their name in Portuguese (*Institutos SENAI de Inovaçao*). To do this, I present results of a comparative analysis of Research and Technology Organizations ("RTOs"), a well-known category of organizations in the national innovation systems of some of the world's most advanced economies, including Germany, the Netherlands, Canada, Finland, Sweden, South Korea, and others. The European Association of Research and Technology Organizations (EARTO), defines RTOs mission as follows:

> "The core mission of Research and Technology Organizations is to harness science and technology in the service of innovation, to improve quality of life and build economic competitiveness" (EARTO, 2015).

The long-term vision for the functions that ISIs are expected to perform within Brazil's innovation system is consistent with patterns observed in these RTOs as well as those in other countries and regions. In fact, SENAI's creation and long-term vision for the ISIs is based on Germany's Fraunhofer Society. Furthermore, within SENAIs Innovation and Technology Unit at the National Directorate (UNITEC), implementation of these institutes is led by a number of Brazilian alums of the Fraunhofer Institute for Production Systems (IPK for its name in German).

This paper joins a surprisingly scarce body of work on RTOs as objects of academic research and targets of policy action. From an academic research perspective, examples include a detailed history of TNO (van Rooij, 2013), transformation of RTOs in Finland (Loikkanen et al., 2011), and Asia and Europe (Sharif et al., 2011); a comparative overview of several RTOs (Mina et al., 2009), an analysis of RTO practices in the Basque Country (Albors-Garrigos et al., 2010), a "triple-helix" analysis of research commercialization in Finland (Suvinen et al., 2010), RTO support for basic industries in Russia (Thurner et al., 2013) and Chile (Lyytinen, 2012). Other studies include perspectives on knowledge management (Mirnalini and Nath, 2008), intangible assets (Leitner, 2005), strategic planning (Arnold et al., 1999), and an RTO role in the emergence of an industry cluster (Holbrook et al., 2010).

In terms of industry and innovation policy, the European Union, EARTO, and several national governments have commissioned studies to examine and enhance the role of RTOs within their national innovation systems. These include reports by Hales (2001) for the European Commission, the Technopolis Group for EARTO (2010) and the Hauser Report in the United Kingdom (Hauser, 2010). For policymakers, the creation of RTOs represents one more tool in the repertoire of organizational forms that can be deployed to improve innovation, with the end goal of enhancing economic prosperity and competitiveness. Thus, while motivated by the creation of the ISIs in Brazil, this work contributes to advancing our understanding of RTOs as organizational actors in innovation systems in general, and at the same time to articulate relevant practices and considerations for their creation and operation in Brazil and elsewhere.

1.1 Cases

The core of this analysis builds upon an examination in particular of the Fraunhofer Institutes in Germany and the Netherlands Organization for Applied Scientific Research (TNO). Additional insights were drawn from Canada's National Research Council (NRC) and the Technical Research Centre of Finland (VTT). Key insights for the Fraunhofer analysis were drawn from an in-depth examination of the organization and history of Fraunhofer performed by Dr. Ylmaz Uygun, now a professor at Jacobs University Bremen in Germany. The analysis was similarly enriched, and its findings validated, through several conversations with key stakeholders in Brazil and the project team at the MIT Industrial Performance Center.

Our initial analysis also included the Catapult Programme in the United Kingdom, the Electronics and Telecommunications Research Institute (ETRI) in South Korea, and the Research Institutes of Sweden (RISE). The analysis was narrowed down to the Fraunhofer, TNO, NRC, and VTT for several reasons. First, all of them have a broad scope and seek to impact and assist all established and emerging industries in their respective economies, without being narrowly specialized in a single technology (like ETRI). Second, there is an abundance of detailed and comparable operational and programmatic information publicly available, as well as reports and publications about each of them.

In addition, each of these RTOs chosen for this analysis has specific relevance, or insights and lessons to to offer for the implementation of ISIs in Brazil. Fraunhofer, is evidently important as the model that SENAI is following. TNO is older than Fraunhofer, just as established, and –our analysis suggests– more nimble as an organization and network of RTOs. The case of NRC is relevant as a national network of institutions operating in a vast country (Canada), just as the ISIs are envisioned to be. TNO and NRC both have significant experience with SMEs, which our industry research in Brazil highlight as a significant opportunity for the ISIs to have an impact. Finally, VTT has been an actor in Finland's transformation from a resource-based economy into a knowledge economy. Taken together, a comparison of these four cases helped reveal similarities and differences across the various themes explored in this study (i.e. funding, work with SMEs and startups, etc.), while also offering unique lessons for the ISIs in Brazil.

2 Understanding RTOs

2.1 Mission and Focus

The European Association of Research and Technology Organizations (EARTO) lists more than 97 RTOs among its members, located in 24 countries (see appendix). They range from large, well-established networks (or consortia) of organizations with a few thousand employees, to stand-alone, relatively small and highly specialized operations that employ no more than 100 people. EARTO defines RTOs as follows:

> The core mission of Research and Technology Organization is to harness science and technology in the service of innovation, to improve quality of life and build economic competitiveness (EARTO, 2015).

In contrast with Scientific Research Institutes and Government Laboratories (see Table 1 for a comparison and examples), the Technopolis Group (2010), an innovation research and consultancy group in Brussels, describes the main focus of RTOs in three terms:

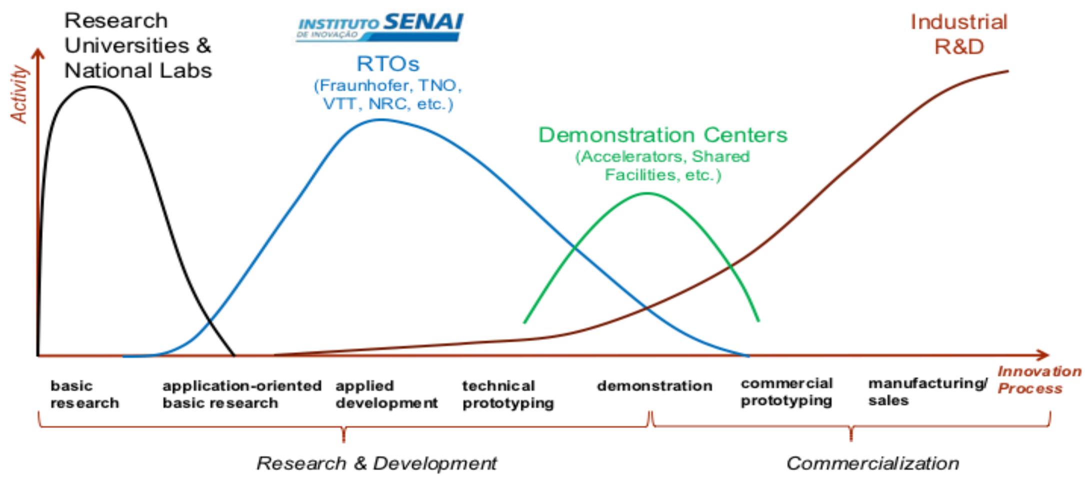
1. Tackle the needs of industry for knowledge-related services.
2. Focus on user or problem-oriented research for the benefit of society.
3. Assume some of the risks of industrial innovation, helping companies go beyond what they would be able to do alone.

2.2 Positioning in Innovation Systems

A national system of innovation, "is that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which government forms and implements policies to influence the innovation process" (Freeman, 1995). In an NIS, public and private actors interact to create, modify, and focus new technologies (Edquist, 1997). Importantly, the economic structure and institutional setup of an NIS provides a context for learning in an economy (Lundvall, 1992).

The backbone of an innovation system is the business sector, which "is the central axis of the process of transformation and innovation", while a supporting structure of organizations such as universities, laboratories, and policy-related institutions contributes to the ongoing transformation (Teubal, 2002). RTO are organizations in the supporting structure. If we think of various actors (institutions, organizations, companies, individuals) in an innovation system as positioned along a spectrum between basic research and the marketplace, different actors engage in distinctive activities and functions. As illustrated in Figure 1, the activities of RTOs allow them to bridge basic research with the application and commercialization of technologies.

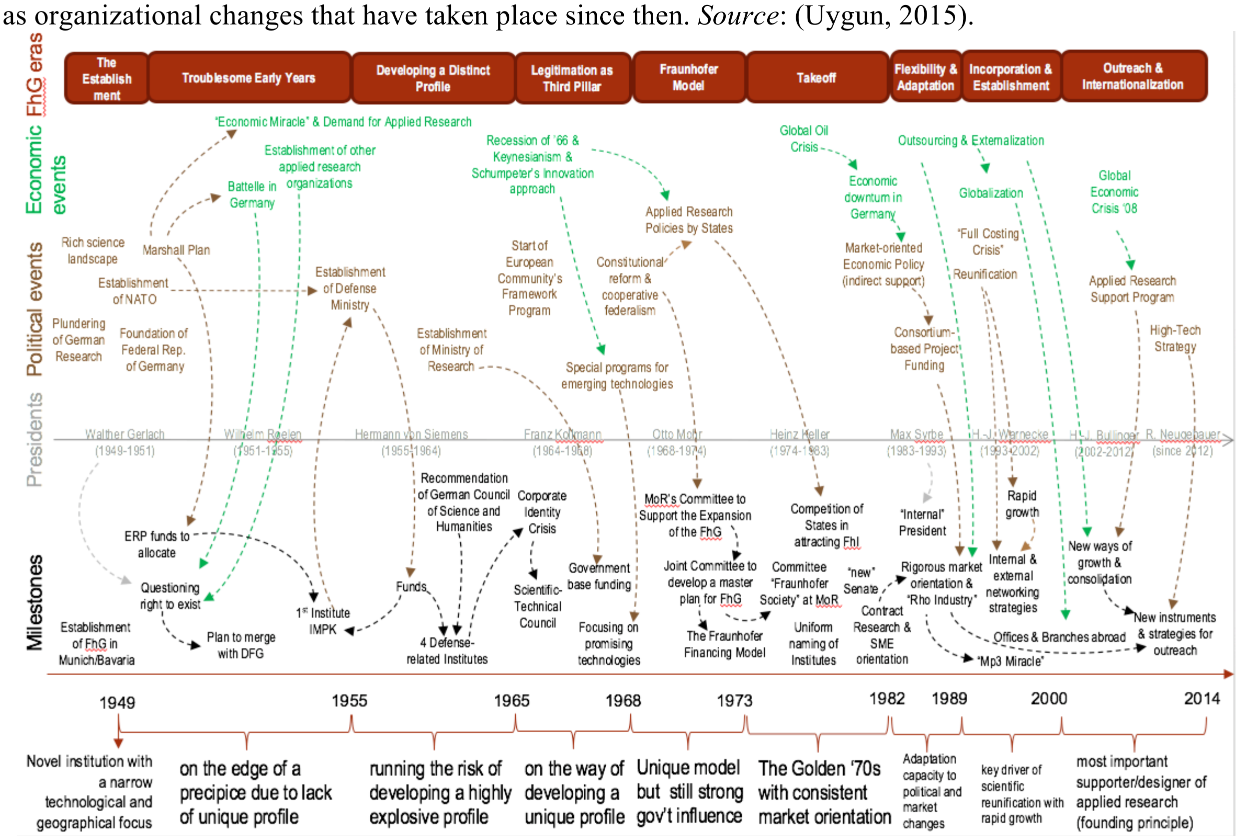
Figure 1. RTOs bridge basic research with commercial and industrial application. Based on (Uygun, 2015).



It is precisely for their ability to bridge between knowledge created through basic research and the marketplace that Brazil, as most countries that have established them, supports the creation and operation of RTOs. In terms of innovation policy, the creation and strengthening of RTOs is a response to three objectives. First, RTOs activities are seen as the vehicle to help translate R&D outcomes into innovations and in that way materialize the economic benefits of public investment in research. The second policy objective is to support new business formation and industrial innovation. RTOs are a response because they are bridges and translators between research communities in universities and laboratories with industry and, to some extent, entrepreneurs, and as performers of applied R&D that has industrial and commercial applications in mind from the start. The third policy objective is to improve the overall competitiveness of the economy through innovation. The creation of ISIs in Brazil embodies these three long-term goals.

As actors in an innovation system (national, regional, or sectoral), RTOs, as are embedded in a context that shapes them. This implies, on the one hand, that RTOs are artifacts of history shaped by culture, politics, power structures, and a changing economic landscape. And, on the other hand, that the internal operations of RTOs and their interactions with other organizations are affected by organizational routines and procedures, and by a legal and regulatory framework. A good illustration of the many forces that shape the evolution of RTOs comes from Uygun's detailed analysis (Uygun, 2015) of the evolution of the Fraunhofer Society. In it, Uygun defines several "eras" for the Fraunhofer society, and captures the interplay of political and economic events as well as key milestones in the evolution of Fraunhofer's mission since its founding in 1949. Figure 2 below underscores the challenges and uncertainty that the Fraunhofer model faced in the early years of its development.

Figure 2. Fraunhofer's development since 1949, illustrating the numerous political and economic, as well as organizational changes that have taken place since then. *Source*: (Uygun, 2015).



2.3 Activities

Within their position in an innovation system, RTOs support the innovation process by engaging in activities. Below are examples of the activities that RTOs engage in.

- *Ideation*. Ideation, technology foresight.
- *Research*: Basic research, applied research, contract research.
- *Development, demonstration and production:* product development, prototyping, proof of concept, compliance, technical support, pilot projects and plants, production process development.

- *IP Protection and Commercialization:* patenting, IP portfolio management, licensing, commercialization.
- *Business and market development:* entrepreneurship and startup support, market identification, business model innovation.
- *Collaboration and networking:* convening interest groups, networking sessions, university collaboration, faculty exchange, researcher exchange.
- *Funding:* grant funding for projects, seed funding, subsidized services.

This list of activities is not comprehensive and not all RTOs perform all activities. Specific institutes within an RTO system may perform only a handful of activities adjusted to their capabilities, goals and markets. Others may have a larger scope.

2.4 Funding

Although there are outliers, RTOs share a pattern of funding. In its recent report, EARTO finds that the average distribution of sources of funding in RTOs is as follows:

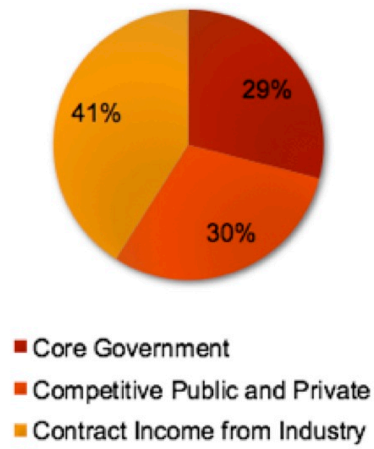
- 29% Core Government: This is a line item in national or state governments. Its purpose is to support capability building.

- 30% Competitive Public and Private. These are funds accessed through competitive solicitations or grants from either public agencies or private entities. Applications for funding may be done together with partners in industry or universities, and the purpose is technology development.

- 40% Contract Income from Industry. These are customer revenues from contracts, primarily with industry. The purpose diffusion, application, or dissemination of knowledge for a specific purpose.

Thus, almost **60% of RTO funding comes from public sources**, half of which is dedicated, line-item funding that is constant and non-competitive. And, as will be described in more detail later, the balance between these three sources of funding has implications for the kinds of impact that RTOs can have on innovation. See Figure 3 below.

Figure 3. Average Funding Scheme of EARTO Members. *Source*: EARTO (2015)



2.5 Projects

The organizing unit of work at RTOs is the project. Using TNO and VTT as the key examples, three typical kinds of projects emerge:

1. *Competence Building*. These projects aim at building expertise and technical capabilities that are perceived to be important for the future of industry and innovation. These projects are funded through core public funding.
2. *Applied Research and Technology Development*. These projects have a purpose in mind, such as product development or the application of a new technology in a production process. Funding is mixed, often involving competitive public funding (available through grants) and private funding from clients.
3. *Application*: These projects involve improvements in existing products or processes, troubleshooting, or consultancies with specific goals in mind. Funding comes from clients, and they are intended to add value quickly, in the short-term.

Through these kinds of projects RTOs achieve a balance between responding to industry needs in the short-term, and having a long-term impact by developing capabilities that help industry stay ahead of known global technology trends.

3 Themes, focus areas and capabilities

A common feature of all the RTOs examines is the way they organize their expertise internally and communicate what they are capable of doing to the public. Three levels of classification may be identified across all of them:

1. *Themes*. These are mostly the big challenges and opportunities of our times, common to every society and economy. Examples include health, the environment, sustainable energy, urban mobility, and the digital economy. These labels can be easily communicated to RTO stakeholders and the public, in that way facilitating an understanding of the relevance of what RTOs do. Table 1 below lists themes.

2. *Focus areas*. Within themes, RTOs have focus areas. For example, within the theme of mobility and urbanization, focus areas could include automotive technology, rail technology, aviation, mobility research, smart cities, smart governance, and build environment (to name a few). See Appendix A for a comprehensive list of focus areas.

3. *Capabilities*. In order to act upon themes and focus areas –solve problems, develop products, create solutions for industry and society, etc.– RTOs have capabilities. These are literally what RTOs are capable of doing in practice with the experts that work with or for them, or with the equipment they own or have access too. Capabilities can be specific to a vertical (i.e. biomanufacturing pilot plants, solar PV system testing) or horizontal, applicable to multiple industries (i.e. modeling and simulation, waste treatment).

3.1 Themes and Focus Areas

The stated mission to contribute to industrial innovation and to benefit society and quality of life in general– is manifest in the themes and focus areas of RTOs. Table 1 below shows the overall or high-level themes that key RTOs reviewed for this study currently focused on, while Appendix A lists the focus areas within each of these themes for different RTOs.

Table 1. Current priority themes at Fraunhofer, TNO, NRC, and VTT. Available online.

Fraunhofer (Germany)	**TNO (Netherlands)**	**NRC (Canada)**	**VTT (Finland)**
• Health and environment • Security and protection • Mobility and transport • Production and supply of services • Communication and knowledge • Energy and resources	• Industry • Healthy Living • Defense, safety, and security • Urbanization • Energy	• Agriculture and aquaculture • Astronomy and astrophysics • Construction • Defense and security • Energy, mining and environment • Health sciences • Information and communications	• Bioeconomy • Health and wellbeing • Digital society • Low carbon energy • Smart industry • Sustainable and smart city • Business development

		technology • Metrology • Transportation	

Several patterns emerge by comparing these themes and focus areas. First, that there are themes that are of interest across these RTOs. Taking a closer look at these their respective focus areas in Appendix A, these themes across the four RTOs may be grouped in the following categories:

- Health and wellbeing
- Energy, resources and the environment
- Mobility, transportation, and urbanization
- Digital technology (information and communications technologies)
- Industry and production systems
- Defense, safety, and security
- Agriculture, aquaculture, and the bioeconomy

The second insight is that a common theme (i.e. energy, resources, and the environment) does not necessarily reflect the same focus areas in all RTOs –although there are also common focus areas. Some focus areas reflect the reality of the national economy, existing or desired strengths within established national industries, new capabilities for these industries, or entirely new industries.

Third and finally, focus areas within themes range from new and emerging sectors like robotics, flexible electronics, and digital health, to established or legacy industries such as automobiles, agriculture and buildings. As much emphasis as there is today in these emerging industries, the priorities of these RTOs also reflect a perceived potential for innovation in existing industries. In short, a focus on emerging areas and future industries does not mean neglecting or abandoning the segments of the economy that already exist.

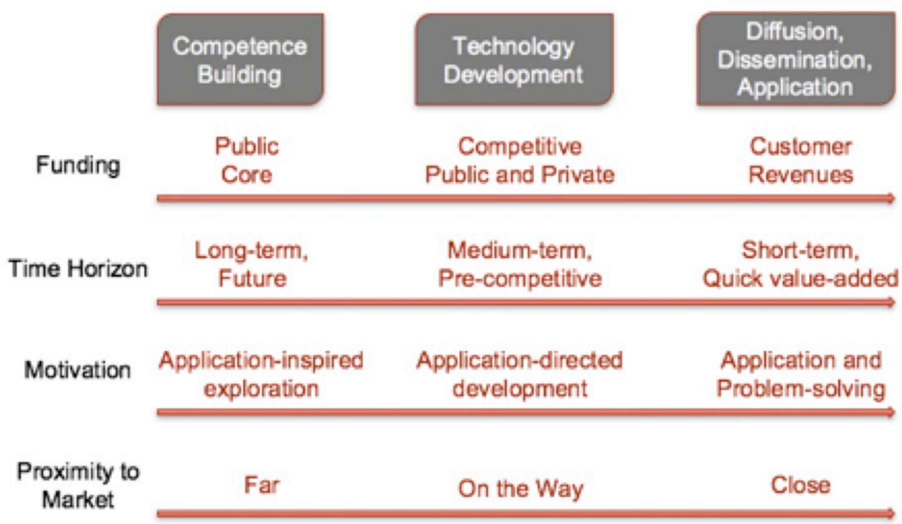
3.2 Capabilities

RTOs mobilize capabilities –highly specialized areas of expertise embodied in people or equipment– around specific projects. (As an illustration, Appendix B lists TNO capabilities). Capabilities are mostly in house, but can also be accessed from other organizations (such as universities or government laboratories) on a project-by-project basis. In this way projects are not only the organizing unit of work for RTOs. Projects are also the arenas for collaboration between RTO personnel, industry practitioners, and in many cases researchers, engineers, designers and other specialists usually from universities or other specialized organizations. Through their interactions in the context of projects, they mobilize and apply capabilities to create solutions for specific problems in a company or a whole industry.

Project-based work afford RTOs the ability to respond and mobilize capabilities in a flexible and customized way. Importantly, it allows RTOs to assemble projects that bring together a unique set of capabilities (people and equipment), according to the goal of this project. As illustrated in the work of Zylberberg and Lima in the ICT and oil and gas industries, (accompanying working papers), each project is indeed unique, and can involve different kinds of clients, sources of capabilities, and outputs.

The sources and uses of funding described earlier align with the three main types of projects just described. On one end of the spectrum, core public funding supports RTOs ability to build new capabilities whose relevance for industry or the marketplace may not be immediately evident. However, being for "application-inspired" projects, they have a future application in mind. TNO for example, has a publicly-funded early research program developing capabilities in areas such as quantum computing, personalized food and health, and 3D nanomanufacturing instruments. These programs often involve the typical performers of basic research, such as government laboratories and universities. On the other end of the spectrum, projects launched to solve a specific problem or serve a customer request are typically funded by the customer, and are expected to have an impact in the short-term. In this case, there is no ambiguity in the purpose of the project. It has a clear purpose, and its goal is to add value as quickly as possible.

Figure 4. RTOs' project portfolio balance immediate industry needs with capability-building for the future. *Source*: Author's inspiration, with initial framework by EARTO (2015).



This interplay between funding sources, types projects, and capabilities has profound strategic implications for RTOs, and it is particularly relevant for an RTO network like the ISIs. The main implication is that *focusing only on projects that serve immediate and clear client needs while relying only on customer revenues is unlikely to yield the kinds of innovation that RTOs are usually created for in the first place*. Balancing this ability with the ability to develop or to access more future-oriented capabilities, and their application in applied research and technology development projects, is essential for RTOs to have the kinds of impacts that help industry keep abreast, and ideally ahead, of global technology trends.

3.3 Adaptation and foresight

Technological and social change, industrial evolution, and an ever-changing list of small and big challenges and opportunities, mean that neither themes, focus areas, nor capabilities are permanent. Themes may be durable, but within them, new focus areas may require developing new capabilities while leaving others behind. Within the health theme, for example, personalized medicine is a transformative development and opportunity. For an RTO to pursue it, it may need to adopt or upgrade capabilities in genomics and computation (among others).

4 Working with SMEs, Startups, and IP Commercialization

4.1 SMEs

RTOs offer a distinctive portfolio of innovation support and services to **SMEs.** This portfolio includes activities such as: advisory services, facilitating access to growth capital, networking, access to markets, and management training. Importantly, they support SMEs via innovation-related work by granting access to equipment and experts in activities such as product development, process design, prototyping, testing, certification. Active outreach and creative funding approaches are required, because SMEs often do not have the capacity or the resources to partner with an RTO in an innovation program. Dedicated personnel are key to the engagement of RTOs with SMEs. In one of the most prominent SME programs, Canada's Industrial Research Assistant Program (IRAP), administered by the NRC, a cadre of professionals called "Industrial Technology Advisor" serve as the liaisons with SMEs.

4.2 Startups

The observed forms of RTO participation in **startups** fall into two categories: (1) providing support to startups and entrepreneurs by facilitating access to experts and equipment and (2) spawning startups to commercialize IP created within the RTO. In both cases, making money is not the primary RTO objective when supporting or helping create startups. Instead, it is part of the mission of having a practical impact on innovation and the betterment of the economy and possibly society.

4.2.1 Support for startups and entrepreneurs

The first case involves assisting startups (and sometimes hosting them in an RTO) and providing personnel support as well as shared equipment and mentorship. An example of this approach is TechBridge, a program created by Fraunhofer USA Center for Sustainable Energy Systems

(Fraunhofer CSE) in Boston, MA.[1] This program was created to support clean energy startups and describes itself as an “R&D focused accelerator program for cleantech entrepreneurs.” The program is organized around *challenges*, each funded by public and private sector sponsors. Fraunhofer CSE works with sponsors to define each challenge, and subsequently engages in a global startup search and selection process. Experts from Fraunhofer provide assistance in the design of validation or demonstration projects that help advance the technology to the marketplace. In the process, Fraunhofer CSE can access capabilities throughout the Fraunhofer network. The projects are executed at Fraunhofer facilities (by Fraunhofer personnel), and may involve real-world settings.

An example of a challenge is the recent SunRise TechBridge Challenge, launched to seek alternatives to lower the cost of energy in PV systems. The program was launched in partnership with Royal DSM, a Dutch industrial conglomerate. For selected startups Fraunhofer CSE provided one or a combination of: $100,000 in technical validation services, an incubation and acceleration program with up to $130,000 in in-kind support by Greentown Labs (A Boston-based clean energy incubator, and a partnership or venture funding from Royal DSM.

4.2.2 Spawning startups to commercialize IP

The second case involves supporting all the steps required to create a new business: IP agreements, management advice, etc. Two examples stood out from this analysis: TNO Companies and Fraunhofer Venture.

TNO Companies was founded in 1987 and operates as a private company that is legally, financially, and administratively separate from TNO, but it is wholly owned by TNO. It operates as a holding company, currently of nearly 80 privately-owned spinoffs. Its objectives, as described by TNO companies are “focused on getting the pioneering scientific knowledge TNO develops to market,” as well as the “valorization of TNO knowledge when others are not willing or able to do this independently.” Its end goal is sell those companies and use the proceeds for further investment.

TNO Companies holds three types of companies:

1. *Spinoffs of developments at TNO*. These are companies whose products or services build upon TNO developments, and incorporates partners in a new venture. They go through an acceleration process and the final goal is a successful exit by TNO Companies and investing partners.

[1] This paragraph is based on information available in Fraunhofer CSE’s website. More details available at: http://www.cse.fraunhofer.org/techbridge.

2. *Autonomous companies*. This are entire R&D units that are spun-off and incorporated in a separate company. It is virtually the same as the privatization and subsequent sale of TNO capabilities.

3. *Start-ups*. These are companies created by entrepreneurial TNO employees. TNO Companies has a partnership (and is co-owner) of Yes!Delft, the incubator/accelerator program of the Technical University of Delft. The goal is to help the entrepreneur and startup with an incubation and accelerator program, while providing community, coaching, networking, and connections with potential investors.

In contrast with TNO Companies, Fraunhofer Ventures appears more systematic, as if applying an engineering problem-solving approach to the commercialization of Fraunhofer IP. It was created in 1999 and reports 150 spin-offs since then. With a dedicated staff of 20, it assists Fraunhofer "intrapreneurs" in multiple steps of starting a business. These include business plan development, technology transfer (patents, technologies), establishing legal entities, facilitating industry partnerships, and search for external investors. To support entreprenurs and startups, it provides subsidies of up to €150,000 in seed funding and €100,000 in management support. It also provides technical and management training and workshops. In addition, it has some "promoters" inside Fraunhofer institutes, whose function is to help identify ideas or developments with commercialization potential.

Because startups often have limited resources, RTOs have mechanisms to support or subsidize, at least in parts, the costs that startups would incur by working with an RTO. For supporting existing startups, funds can come from the RTOs own funds (Fraunhofer Ventures), from sponsorship agreements with large companies with an interest in a specific technology area (i.e. robotics for agribusiness, solar cell module manufacturing, green chemistry) (Fraunhofer CSE), or from external investors in combination with own funds (TNO Companies).

4.3 IP Commercialization

An additional important way in which RTOs take IP to commercial or industrial application is simply by making it publicly available (often listed in the website). Both NRC and TNO pursue this approach.[2] This IP can then be taken up by established companies or entrepreneurs. In both cases, having IP management and technology transfer expertise is necessary, as well as clear rules for IP sharing as a starting point for negotiation. Royalty sharing from licensing IP can be negotiated on a case-by-case basis.

[2] For TNO see: https://www.tno.nl/en/collaboration/patents-and-licenses/
For NRC see: http://www.nrc-cnrc.gc.ca/eng/solutions/licensing/index.html

5 Key Challenges and Factors for Success

5.1 Challenges

Our deeper analysis of Fraunhofer and the other RTOs helps to illustrate some key challenges faced by RTOs, which are relevant for the ISIs in Brazil:

1. *Collaboration across institutes*. There are cases in which projects will require capabilities (people and equipment) that are not available in one institute, but may be available elsewhere. Also Institutes are supposed to operate as a network. This is challenging due to local governance and regional markets while operating in a national network.

2. *Interdisciplinary projects*. Industry problems and novel products and services often combine several academic disciplines, technologies, and occur at the intersection of different industries. Institute and disciplinary specialization within institutes poses a challenge when it comes to responding to needs or developing novel products that require crossing boundaries and combining technologies.

3. *Attracting talent*. Due to their applied orientation and emphasis on innovation in industry and the economy, RTOs such as Fraunhofer compete for talent with universities and industry. In the case of Fraunhofer, compensation regimes that tie salaries to those of public servants pose a challenge when competing for talent with industry.

4. *Navigating regional and national politics*. As institutions that receive substantial funding from the public sector, and vehicles for the implementation of innovation policy, RTOs are subject to changing political environments, at both the national level (as networks), and at the regional level, as actors in regional innovation ecosystems.

5. *Internationalization of R&D.* Even though innovation is a localized phenomenon, large companies in particular are no longer subject to national boundaries when it comes to R&D. As companies may choose to develop products or solve problems anywhere, national RTOs need to compete globally not just to help their national industries, but to attract projects from elsewhere.

5.2 Key Factors of Success

This comparative analysis reveals several key factors of success for the RTOs that were compared. These success factors are:

1. *Having a clear, limited mission*. Despite their wide scope of work, the examined RTOs have a clear mission and a limited scope that allows them to focus limited resources on areas where they can make a clear, strategic difference on industry and innovation. They do not try to do everything or be all things to all stakeholders.

2. *Public funding to build long-term capabilities.* Core public funding enables RTOs to create, maintain, and acquire capabilities (areas of expertise, experts, equipment) that may not be of immediate need by companies but are important for the long-term growth of the economy and allows RTOs to help industry keep up or ahead of global technology trends.

3. *Flexible organizing of customized projects*. Within established organizational processes, RTOs respond to specific industry trends, needs or problems by organizing projects that are tailored for the task at hand. There is no one-size-fits-all RTO project approach when it comes to company or industry.

4. *Mobility of personnel across organizations*. RTO projects can involve the use of capabilities and experts that work at other R&D organizations, universities or industry. This involves the flow of students, faculty or industry personnel. Personal relationships, and a legal framework that allows for mobility of people are key. Fraunhofer in Germany and TNO in the Netherlands are deeply embedded within each of their country's respective university community, with professors, researchers, and students participating in projects.

5. *Specialists for different organizational functions*. In addition to highly qualified experts for projects, RTOs have other kinds of specialists. For example, dedicated personnel who serve as point persons for SME project work, or technology transfer and IP specialists.

6 Implications for Brazil and the ISIs

The benchmarking of RTOs through this comparative analysis suggests important lessons, questions and implications for Brazil, the ISIs, and SENAI. These include:

1. *Adapting to Brazil.* The comparison of the cases in this study, together with previous work, show that all RTOs are different. The most evident difference is that they operate within countries and regions, with different histories, cultures, institutions, laws, and industries. In all cases RTOs have evolved to adapt and respond to their specific circumstances. They balance adopting global trends with targeting innovation challenges and opportunities that are unique to their context. For the ISIs, it is imperative that they adapt the German model to Brazil's culture, institutions, and its unique innovation challenges.

2. *Time to Become Established:* RTO networks such as Fraunhofer (Germany) and TNO (Netherlands) struggled in their early years to position themselves and gain legitimacy in the National Innovation System. Achieving legitimacy and stability took several decades. Fraunhofer established 60 institutes in 60 years, while the ISIs are supposed to be in place in only 10 years. In this compressed timeframe, SENAI and the ISIs ought to be strategic about

becoming part of Brazil's National Innovation System *and* its respective regions, and identifying the distinctive capabilities they can offer. Importantly, with limited resources, they can strategically avoid duplicating or competing with capabilities that exist in universities or other research institutions.

3. *Partnerships.* To optimize resources and achieve long-term impact, ISIs need to develop collaboration with universities and other RTOs in their respective regions, particularly when they do not have required capabilities in house or the resources to build them. A strategy that helps access capabilities through partnerships is a plausible alternative to building capabilities in-house.

4. *Funding.* The funding patterns of other successful RTOs raise questions about the expectation that has been placed on ISIs to become self-sustainable solely through client revenues. Balancing long-term innovation impact with tending to short-term industry needs will be a challenge for the ISIs because they do not have the core public funding that enables development of long-term capabilities. The current model is likely to make ISIs focus mostly on short-term problem-solving for industry. In the absence of continuous funding for capability development, or of partnerships to access such capabilities elsewhere, ISIs are unlikely to have a distinctively high impact on innovation capacity.

5. *SMEs*. SMEs offer a significant opportunity for impact for the ISIs. To do this, ISIs need to develop specific outreach mechanisms and personnel to work with them. In particular, ISIs can support SMEs by providing access to experts and equipment to support product and process development. However, SMEs are unlikely to have capacity and resources to work with ISIs at market rates. A decision of the ISI network to work with SMEs will require creative funding approaches that will create incentives for SMEs to engage ISIs innovation projects.

6. *Startups.* If the ISIs intend to work with startups –and it is not clear that they should– they should have the right expectations about sustainability of the strategy and impact. They are unlikely to make money in the short term, and in fact making money from startups does not appear to be the right motivation. Instead, the motivation could be to fulfill their mission of impact on innovation and betterment of society in general. Of course, most startups fail so this must be built into the ISI model. In terms of resources to support work with startups, SENAI's Innovation Call appears to be a good template to help startups (and SMEs), including recent approaches to partner with large Brazilian companies that provide some of the funds.

7.

7 Conclusion

This comparative analysis was carried out under the assumption that the long-term vision for the ISIs is to become Brazil's leading RTO network. As the analysis shows, creating and operating a national network of RTOs is an ambitious undertaking. Our research throughout this project suggests that ISIs have the potential to become significant players in the Brazilian economy and potentially catalysts for change. To do this, ISIs individually, and as a national network, will benefit greatly from establishing a clear vision for their future in terms of what they want to be in the context of the Brazilian innovation ecosystem. This includes, among other factors, defining their competitive advantage in an established innovation system, building collaboration with universities and established RTOs, establishing clear rules regarding IP, developing a viable funding model for the long-term and finally, working independently but in synergy with SENAI as a whole, leveraging existing assets where appropriate.

Appendix A

Themes and focus areas for RTOs examined for this study. Source: Classified by the author and Bruno Bopp with information and reports available online. Key: (F) Fraunhofer, (T) TNO, (N) NRC, (V) VTT.

Theme	Fraunhofer (Germany)	TNO (Netherlands)	NRC (Canada)	VTT (Finland)
• (F) Health and Environment • (T) Healthy Living • (N) Health Sciences • (V) Health and wellbeing	• Medical Technology • Implants, Prostheses, Bioresorbable Materials • Assistance Systems, IT Applications • Pharmaceuticals Development • Regenerative Medicine, Artificial Tissue Models • Nutrition / Food Technology • Biotechnology and Environmental Technology	• Predictive Health Technologies • Food & Nutrition • Prevention, Work & Health	• Biologics and Biomanufacturing • Therapeutics Beyond Brain Barriers • Health Technologies • Natural Health Products • Vaccines and Immunotherapeutics	• Process and Analytical Measurement •[1] • Molecular Diagnostic sensors and reagents • Digital Health • Wearable Technology
• (F) Production and supply of services • (T) Industry • (N) N/A • (V) Smart industry	• Industry 4.0 • Product Development • Materials and Surface • Robotics • Automobile and Plant Engineering • Manufacturing Technologies and Production Processes	• Flexible & Free-form Products • Space & Scientific Instrumentation • Sustainable Chemical Industry • Semiconductor Equipment • Networked Information		• Industrial Process Efficiency and Management • Lifetime productivity and safety • Process and analytical Measurement • Arctic and cold climate solutions • Smart Lighting • Metals and Minerals recovery and reuse • Space Technologies • Digital engineering and efficient products and design • Printed and hybrid manufacturing service • The industrial internet: Productivity game-changer • Simulation • Factory of the future
• (F) Communications and knowledge • (T) N/A • (N) Information and communications technology • (V) Digital society	• Audiovisual Signal Processing • Production, Transmission and Distribution of Media Content • Big Data • Image Processing • Cloud Computing • e-Business • e-Government • Embedded Systems / Ambient Intelligence • Internet of Services / Internet of Things • IT Security • Broadband Communications • eLearning, Edutainment	•	• Multimedia Analytic Tools for Security • Gallium Nitride (GaN) Electronics • Printable Electronics*[1] • Learning and Performance Support Systems • Advanced Photonic Components • Smart Textile and Wearables Innovation Alliance	• Cyber Security • Digital Service Engineering (big data) • Network optimisation and management • Wireless access • Components and Software for mobile device

	and Game • Simulated Reality • Software Engineering			

Table 2 (Continued)

Theme	Fraunhofer (Germany)	TNO (Netherlands)	NRC (Canada)	VTT (Finland)
• (F) Energy and Resources • (T) Energy • (N) Energy, mining and environment • (V) Low Carbon Energy	• Renewable Energy • Efficient use of energy • Energy storage and management • Using raw material more efficiently • Building and Living	• Sustainable Energy • Geo Energy • Maritime & Offshore • Geological Survey of the Netherlands	• Algal Carbon Conversion • Marine Infrastructure, Energy and Water Resources • Bioenergy Systems for Viable Stationary Applications • Energy Storage for Grid Security and Modernization • High-efficiency Mining • Mining Materials Wear and Corrosion • Arctic	• Combined Heat and power • Future energy systems • Liquid Biofuels • Wind energy • Nuclear energy
• (F) Mobility and Transport • (T) Urbanisation • (N) Transportation • (V) Sustainable smart city	• Automotive Technology • Rail Technology • Aviation Research and Transport • Mobility Research • Shipping and Maritime Technologies	• Mobility & Logistics • Environment & Sustainability • Buildings & Infrastructures • Smart Cities	• Aeronautical Product Development Technologies • Civilian Unmanned Aircraft Systems • Reducing Aviation Icing Risk • Working and Travelling on Aircraft • Advanced Manufacturing and Design Systems • Special Interest Group in Blow Molding (SIGBLOW) • Vehicle Propulsion Technologies • Fleet Forward 2020 • Lightweighting of Ground Transportation Vehicles • Marine Vehicles • Rail Vehicle and Track Optimization	• Smart cities energy solutions • Transport • Smart Governance • Built environment
• (F) Security and Protection • (T) Defense, safety and security • (N) Defense and security • (V) N/A	• Sniffer Devices Detect Hazardous Substance • Saving Lives with Disaster and Crisis Management • Robust Buildings and Tunnels • Protecting Infrastructures • IT security • Restoration and Protection of Cultural Property	• Missions & Operations • Force Protection • Information Superiority • Human Effectiveness • Cyber Security & Resilience • National Security & Crisis Management	• Quantum Photonic Sensing and Security • Air Defence Systems • Canadian Security Materials Technologies Roadmap • Security Materials Technologies	•

Appendix B

An example of RTO capabilities, using TNO as an example. The classification on Technical Sciences and Earth, life and social sciences is TNO's own.
Information available at: https://www.tno.nl/en/collaboration/expertise/

Earth, Life and Social Sciences	Technical Sciences
Applied Environmental Chemistry Chemical, Biological, Radiological and Nuclear Protection Child Health Climate, air and sustainability Dino, Data an dInformation of the Dutch Subsurface Dutch Centre for Health Assets Functional Ingredients Geomodelling Human behavior and organizational innovation Life style Metabolic health research Microbiology and systems biology Military operations Modelling, simulation and gaming Networked organizations Perceptual and cognitive systems Petroleum geosciences Risk analysis for products in development Safe and healthy business Smart mobility Strategic business analysis Strategy and policy Sustainable geoenergy Sustainable productivity and employability Sustainable transport and logistics Training and performance innovations Urban environment and safety Water treatment Work, health, and care	Access network technology Acoustics and sonar Business information services Distributed sensor systems Electronic defence Energetic materials Equipment for aditive manufacturing Explosions, ballistics and protection Gas treatment Heat transfer and fluid dynamics Wireless autonomous sensor technologies Flexible electronics ICT Security Instrument manufacturing Intelligent imaging Materials for integrated products Media and network services Nano-instrumentation Optics Optomechatronics Performance of network and systems Integrated vehicle safety Powertrains Process and instrumentation development Responsive materials and coatings Service enabling and management Structural dynamics

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