Khelfaoui and Bernier
Journal of Innovation and Entrepreneurship (2023) 12:52
https://doi.org/10.1186/s13731-023-00321-z

Journal of Innovation and Entrepreneurship

RESEARCH

Open Access

Research and technology organizations as entrepreneurship instruments: the case of the Institut National d'Optique in the Canadian optics and photonics industry

Mahdi Khelfaoui[1*] and Luc Bernier[2]

*Correspondence: mahdi.khelfaoui@uqtr.ca

[1] Department of Human Sciences, Université du Québec à Trois-Rivières, Trois-Rivières, Canada
[2] Faculty of Social Sciences, University of Ottawa, Ottawa, Canada

Abstract

Research and technology organizations (RTOs) are studied in the innovation policy literature mainly as providers of R&D services and as intermediaries between universities and the private sector. Through the case of the Institut National d'Optique (INO), Canada's leading RTO in the optics and photonics industry, we argue that RTOs can also act as entrepreneurs by generating technologies and commercializing them through licensing, technology transfers and spin-offs. By analyzing the broad range of activities undertaken by INO, we also discuss what characteristics make some RTOs more likely to embrace entrepreneurship than others. Those characteristics include the following: renewed access to government funding to build a strong in-house research infrastructure and scientific workforce; strategic R&D planning that incorporates commercial objectives and an environment that encourages a culture of entrepreneurship among employees; the ability to act as the driving force of a network of academic, government and private sector organizations. From a policy perspective, the INO case indicates that the main value of using RTOs as entrepreneurship instruments does not lie in profitability but rather in developing dynamic regional systems of innovation.

Keywords: RTO, Entrepreneurship, Innovation, Technology transfer, Spin-offs

Introduction

Since governments have closely associated technological innovation with economic growth, how to stimulate technology-based entrepreneurship has become a key issue in the design of industry and innovation policies (Brown & Mason, 2014; Leyden & Link, 2015; Wright et al., 2004). Technology-based entrepreneurship is defined as activities directed towards the commercialization of new technology products and services or the creation of new technology firms (Xue & Klein, 2010). Since the 1980s, governments have aimed to stimulate technology-based entrepreneurship by providing funding through tax credits and subsidies to corporate research and development (R&D) laboratories, R&D-intensive small and medium-sized enterprises (SMEs) and multinationals

(David et al., 2000; Feldman & Kelly, 2006; Gonzalez & Pazo, 2008). Public policies have also aimed to generate entrepreneurship through the creation of science and technology parks (Lecluyse et al., 2019), the support of academic entrepreneurship (Shane, 2004), and the subsidization of R&D collaborative programs involving private companies and public research institutions (Adams et al., 2003).

Over the last few decades, governments have also established a number of R&D-intensive organizations with explicit “public good” mandates to support innovation in private firms. These organizations are often called research and technology organizations (RTOs) and cover a broad spectrum of public, semi-public, for-profit or nonprofit institutions (Cruz-Castro et al., 2020). Regardless of their ownership status, most RTOs generate external revenues through R&D services, mainly delivered to SMEs, but still depend on government funding to balance their budgets and leverage private investments (Taverdet-Popiolek, 2022). According to the European Association for RTOs (EARTO), their primary mandate is to provide “research and development, technology and innovation services to enterprises, governments and other clients” (EARTO, 2007, p.3). Despite their importance in innovation systems, RTOs remain relatively understudied in the technology and innovation policy literature (Giannopoulou et al., 2019), and when they are, it is mainly to evaluate their effectiveness in delivering R&D services to SMEs (Barge-Gil & Modrego, 2011; Comacchio et al., 2012; Rincon & Albors Garrigos, 2017; Tann et al., 2004). Yet, while providing customized technology solutions to private firms remains RTOs’ bread and butter, most of them also engage in other types of activities. They can develop medium-to-long-term R&D projects, act as spin-off incubators, achieve technology transfers, develop patent portfolios, and contribute to developing the scientific workforce of a region or country through internship programs.

In particular, little has been said about RTO’s ability to generate in-house entrepreneurship, which can result in the creation of new products, services or firms. In this paper, we address this issue by analyzing the case of the Quebec-based Institut National d’optique (INO), Canada’s largest center of expertise in optical and photonic technologies. The INO case is particularly interesting and relevant to the study of RTO’s entrepreneurship, because it provides a rare example of an RTO that is simultaneously able to *explore* (develop new products and processes) and *exploit* (offer services based on existing products and processes) (Chandrasekaran et al., 2012). In line with the traditional role of RTOs, INO performs several hundred R&D contracts on a yearly basis for a variety of clients, mainly Canadian SMEs. It also develops scientific collaborations with universities and government research agencies and produces a significant number of patents relative to the size of its scientific workforce. More importantly, INO stands out from other Canadian RTOs in successfully completing technology transfers and creating a number of spin-off companies, some of which have become major players in Canada’s optics and photonics industry. In this regard, although subsidized by public funds, INO demonstrates an entrepreneurial orientation that is more commonly associated with private sector behavior.

In the following sections, we first discuss why RTOs should be given consideration as entrepreneurship instruments, especially when compared to universities, which have been commonly used to fulfill this policy role through academic entrepreneurship. We also discuss the characteristics that make some RTOs more inclined to adopt an entrepreneurship approach than others. Building on these theoretical considerations, we underline INO's origins and evolution as a nonprofit RTO that simultaneously incorporated public policy and commercial goals. Using several archival documents, we document how its relationship with universities, government agencies and private businesses have enabled it to occupy a pivotal position at the frontier of the public and private sectors and develop an entrepreneurship dimension alongside its research and service-oriented activities. Finally, using quantitative data, we analyze INO's patterns of scientific and technological collaborations, its sources of revenues, and the characteristics of its technology transfers and spin-offs to identify the factors that have enabled it to successfully conduct commercial activities.

Literature review: RTOs and entrepreneurship

Since the enactment of the Bayh-Dole Act in the U.S. in 1980, universities have been increasingly encouraged to collaborate with private companies (Sjöö & Hellström, 2019) and generate entrepreneurship through licensing, patenting and the creation of start-ups and spin-offs (Di Gregorio & Shane, 2003; Mathisen & Rasmussen, 2019). However, despite significant efforts (Etzkowitz et al., 1998; Rothaermel et al., 2007) and documented successes in terms of knowledge transfer to the industry (Miller et al., 2018), academic entrepreneurship has generally yielded mixed results in terms of start-up and spin-off creation (Harrison & Leitch, 2010; Siegel & Wright, 2015). On the other hand, while their primary role has been "more focused around the support for innovation in companies than being the source of new innovations" (Charles & Stancova, 2016), RTOs have also experienced increasing pressure from governments to commercialize and internationalize their own products and services (Sharif & Baark, 2011). Even though RTOs are more market-oriented than universities, research on their entrepreneurship has been limited, probably, because they have long been considered as lacking the resources and capabilities to innovate like private businesses and perform basic research like academic institutions (Arnold et al., 1998). Indeed, RTOs are often conceptualized as "intermediary organizations" (Howells, 2006), i.e., organizations that only fulfill "intermediary functions" in innovation systems, such as applied research, product development, problem solving, technical assistance, and engineering services for the industrial sector (Hecklau et al., 2020; Readman et al., 2018).

Yet, apart from their role as intermediaries, RTOs can generate basic and applied knowledge and then translate it into marketable innovations, thus acting as technology entrepreneurs. Activities, such as intellectual property development, protection and commercialization or business and market development, including entrepreneurship and start-up support, have been identified as generic activities that can be undertaken by RTOs (Martinez-Vela, 2016). In this regard, Gullbrandsen (2011) notes the dual character of RTOs, describing them as "hybrid organizations" that incorporate values and cultures from both academic research and the public sector, on one hand, and from industrial research and the private sector, on the other hand. Moreover, while universities generate new knowledge regardless of its immediate effect on firms' innovation capabilities, RTOs' main driver of helping private enterprises improve their competitiveness also enables them to acquire finer-grained knowledge of the markets in which they are active. Finally, RTOs have a greater "cognitive proximity" to private firms than universities, and they can, therefore, better "understand and translate business needs and scientific knowledge into incremental outputs" (Giannopoulou et al., 2019). In short, considering that most RTOs usually develop a deep knowledge of the academic, government and industrial sectors in which they operate, and given their more pronounced market orientation, it could be argued that they could be at least as effective as universities in generating entrepreneurship.

That being said, RTOs cover a broad spectrum of R&D organizations, with varying sizes, budgets, missions and approaches to innovation (Breznitz et al., 2018), and they may not all be suitable entrepreneurship instruments. One could then ask whether there are certain characteristics that make some RTOs more suitable for entrepreneurship than others. Put differently, answering this question involves looking for the specific conditions that would enable RTOs not only to support innovation in other organizations but also to generate it internally. Giannopoulou et al. (2011) started answering this question by identifying internal and external drivers for the development of service innovation capabilities within RTOs: the level of government support provided to the RTO; the RTO's strategy, including the definition of "clear strategic innovation objectives"; the RTO's organizational assets, such as intellectual and relational capital; and the intensity of relationships developed by the RTO with universities and the industry. Let us further discuss these four drivers.

The level of financial support provided by the government to an RTO and, more broadly, the nature of the relationship between them are mainly defined by the RTO's ownership type (public, semi-public, nonprofit, private). The ownership type determines the level of revenues, excluding government funding, that an RTO must generate to balance its books. The nature of the relationship between governments and RTOs can also influence their mission and objectives (more research, service or business oriented), scope (specializing in targeted technological sectors or adopting a more open and generalist approach), and business models (Landry et al., 2013). It has been argued that when RTOs operate more or less at arm's length from the government—for instance, through a non-profit status requiring them to generate a significant part of their revenues—their commercial and entrepreneurial dimension may take precedence and they may "operate more like a firm than a policy organization" (Charles and Stancova, 2016). This observation is consistent with a recent study (de la Torre et al., 2021) which confirmed that public research organizations with high shares of revenues coming from competitive public funding and private income had higher market influence than organizations which relied mainly on core public funding (Bozeman & Crow, 1990). However, government funding remains paramount for RTOs to build internal R&D infrastructures and programs, which constitute the starting point for future marketable products. In short, the way in which the entrepreneurial orientation of an RTO is influenced by its relationship to the government depends on a complex equilibrium between the degree of autonomy the RTO has to define its commercial objectives and the level of support, especially financial, the government is willing to provide the RTO in order to fulfill those objectives.

The definition of the mission and scope of RTOs influences how they determine their commercial strategies, which may include programs aimed at encouraging innovation and entrepreneurship within the organization (intrapreneurship) or partnering with outside entrepreneurs to bring products or inventions developed within the organization to the commercial stage. Developing entrepreneurship activities requires long-term planning as well as business development programs. In this regard, some authors have argued that to develop technological innovation capabilities, RTOs must devote particular attention to strategic planning (Arnold et al., 1998; Mortazavi et al., 2016). Giannopoulou et al. (2011) also observe that for an RTO to develop "innovation services," employees must be encouraged to develop an entrepreneurial culture that can be institutionalized through structured programs. Examples of such initiatives can be found in the Fraunhofer–Gesellschaft, one of the world's largest and leading RTOs, which in the 2010s launched successful programs to promote the creation of spin-offs by its own researchers as well as by external entrepreneurs (Lambertus et al., 2019). Another major RTO, Australia's CSIRO, launched a program in 2015 to increase the volume of entrepreneurial ventures involving its intellectual property and started a venture capital fund to support its own spin-offs (Intarakumnerd & Goto, 2018). Carayannis et al. (1998) have also observed that spin-offs from R&D government laboratories often involve entrepreneurs from within these organizations. Knowing that RTO researchers value academic research as much as its commercialization and seem more motivated by entrepreneurial challenges than their colleagues in universities (Suominen et al., 2021), all the above examples indicate that intrapreneurship might be well-suited for RTOs.

Knowledge attributes of staff and knowledge capitalization practices, such as retaining experienced employees and capitalizing on their professional networks, have also been found to be positively correlated with RTOs' in-house innovation capabilities (De Silva et al., 2019). While it has been suggested that RTOs with a strong commercial focus favor patenting over publishing scientific articles (Bienkowska et al., 2010), a study of a large sample of Russian RTOs also brought out a positive relationship between RTOs' scientific output (measured by the number of articles published in scholarly journals) and their ability to complete technology transfers (Zaichenko, 2018). The INO case seems to indicate that both patenting and publishing scientific articles contribute to developing RTOs' entrepreneurial dimension. Some research-oriented RTOs indeed engage in long-term R&D projects which may ultimately result in generating a business activity, as illustrated by the development and licensing of the well-known mp3 audio format by the Fraunhofer–Gesellschaft (Comin et al., 2018). In short, RTOs can take advantage of their in-house R&D capabilities, human and intellectual capital, as well as scientific collaborations to engage in entrepreneurship (Lambertus et al., 2019).

Based on a survey of European RTOs, De Silva et al. (2019) also found that the relationships developed by RTOs with universities, government agencies and private companies through research collaborations, business ties, formal and informal networks contributed to their ability to generate financial (commercial revenues, research grants) and non-financial (new knowledge, social capital) value, which can in turn be harnessed for entrepreneurship purposes. An important factor contributing to non-financial in-house value generation is the ability of RTOs to shape the orientation of the innovation ecosystems in which they operate. RTOs can indeed play "a central role in the development of particular cluster groupings through their specialization around core technologies" (Charles & Stancova, 2016, p. 80). It may, therefore, be expected that RTOs that develop dense networks of relationships with different partners and, more importantly, are able to influence their innovation strategies will be in a better position to develop entrepreneurship activities.

To sum up, the level of engagement of RTOs with entrepreneurship depends on several factors which will be explored in the case of INO by answering the following three questions: (1) what is the nature of the relationship built through time between INO and the governments of Canada and Quebec and how does this relationship affect INO's entrepreneurship; (2) how are INO's commercial goals related to the mobilization of its intellectual capital, notably through encouraging innovation among its employees; and (3) what are the scientific and business ties that INO have developed and maintained with universities, government agencies and private enterprises and how these ties have influenced its entrepreneurship.

Methods and data

Recognizing the existence of a wide variety of RTOs and the diversity of their missions and goals, we do not pretend that all RTOs can or should generate in-house entrepreneurship, but rather try to understand what the characteristics of entrepreneurial RTOs are. To answer this question, we rely on the case study method to analyze the characteristics of INO which, in the Canadian context, stands out from other RTOs in its ability to generate entrepreneurship. While applying a statistical model on a large population of RTOs could help establish probabilistic levels of confidence and correlations between the entrepreneurship capabilities of RTOs and a certain number of variables, such as access to government funding, a descriptive case study, although limited to a single or limited number of cases, offers an in-depth understanding of the political and economic contexts, social processes and causes that are related to a given phenomenon, which a statistical study cannot provide (Flyvbjerg, 2011). Thus, analyzing INO as an exemplar case of an entrepreneurial RTO will provide a context dependent (Flyvbjerg, 2006) but nonetheless valuable knowledge to the innovation policy literature on RTOs which has up to know considered them mainly as intermediary organizations in innovation systems rather than entrepreneurship instruments.

To conduct our study, we relied on both qualitative and quantitative data. The qualitative data were constituted through a systematic review of all the publicly available documents published by INO as well as documents published about INO between 1985 and 2022. The documents published by or about the organization were obtained through different sources. Several internal policy documents, strategic plans, bulletins, government evaluation reports, annual reports, and INO's board of administrators' minutes of meetings from the 1980s and 1990s were accessible at the National Library and Archives of Quebec (BAnQ). We also contacted INO to access their annual and financial reports from 2000 onward. We completed these data by extracting from two general and business press databases (Eureka.cc and Dow Jones Factiva) all the articles published about INO in the Canadian trade press between 1985 and 2022. This body of qualitative data allowed us to extract a large quantity of information including strategic planning documents, annual reviews of INO's research and business activities, annual breakdowns of its expenses and revenues, the list of its technology transfers and spin-offs, as well as programs documenting INO's links to academic, government and private sectors organizations.

The quantitative data first consisted in collecting all the scientific publications published by INO between 1985 and 2021 from the Google Scholar database as well as all its patents which are all listed on its website.[1] Regarding the scientific publications, INO first sent us a list of 796 publications (including peer reviewed articles, book chapters, and conference proceedings) published by its researchers between 1985 and 2018. We retrieved these publications in the Google Scholar database by searching their titles. With access to the full documents, we were able to extract the affiliations of all the coauthors of a given publication. This allowed us to identify which publications were coauthored solely by INO researchers and which ones resulted from collaborations with researchers affiliated with universities, government agencies, or private enterprises. We repeated the same operation for 34 papers published between 2019 and 2021, except that we had to find these publications ourselves by first looking for authors with an affiliation to INO in the Google Scholar database. In short, we used INO's scientific publications mainly to analyze the evolution through time of it patterns of collaborations with universities, government agencies and private enterprises. We used the 343 patents that we extracted from INO's website mainly to determine the evolution of the organization's patenting activity through time, and also to determine the country or region of their assignment, which is an indicator of the internationalization of INO's commercial activities and markets. Finally, through several Internet queries, we collected data on the characteristics of INO's spin-offs, including information for the latter on their founders, locations, revenues, number of employees and patents owned as of 2022.

The origins of INO: a public instrument between science technology and industry

In this section, we review the origins of INO in the specific context of Canada's and Quebec's science and technology policies during the 1980s. We show how INO's relationships with public and private sector partners influenced its organizational structure, mission, objectives and even choice of location, which were all designed to incorporate a business and entrepreneurship dimension, even though INO's objectives never included profit maximization.

In the 1980s, Quebec was the Canadian province that made the most use of RTOs. The provincial government's science policy shifted towards technological development, with the aim of ensuring that academic research served economic growth. Known as "the technological turn," this policy led to the extensive use of new policy instruments, such as R&D tax credits to SMEs and the establishment of technology transfer centers, to facilitate knowledge flows from universities to private industry (Fortin, 1985). In addition, from the mid-1980s to the late 1980s, several RTOs were established by the Quebec government to generate basic and applied knowledge, provide R&D services to SMEs, and contribute to the emergence and consolidation of industries in targeted high-technology sectors (Godin & Trépanier, 1995). They included the Centre québécois pour la valorisation de la biomasse (CQVB) in the biotechnology sector, the Centre de recherche

[1] The patents are listed under: https://www.ino.ca/en/resources/patents/ (last accessed 10 April 2023).

Table 1 Main Canadian RTOs in terms of total revenues generated

RTO	Province	Year created	Employees	Ownership type	Avg. total revenues (2014–21) in $M	Avg. net revenues (2014–21) in $M
Alberta Innovates	Alberta	1921	670	SOE	257.1	-14.5
Saskatchewan Research Council	Saskatchewan	1947	340	SOE	80.5	0.37
Research and Productivity Council	New Brunswick	1962	160	SOA*	14.2	0.42
Centre de recherche industrielle du Québec	Quebec	1969	209	SOE	32.2	1.67
Industrial Technology Center	Manitoba	1979	N.A	SOE	2.4	-0.04
Institut National d'optique (INO)	**Quebec**	**1985**	**200**	**Nonprofit**	**37.7**	**0.94**
Centre de recherche en informatique de Montréal	Quebec	1985	60	Nonprofit	9.2	0.18
FPInnovations	British Columbia/ Quebec	2007	430	Nonprofit	80.3	2.17

Bold values are denoted the RTO that is studies in this paper (INO)

*Special operating agency (government-owned). Source: 2014–2021 annual reports of the RTOs present in this table

en informatique de Montréal (CRIM) in the information technology sector, and INO in the optics and photonics sector. During the 1980s and 1990s, new public management ideas, which gave more credit to private organizations as engines of economic growth, became influential within the Canadian and Quebec governments (Aucoin, 1995). As a result, most of the newly created RTOs were designed to operate as nonprofit organizations to give them more flexibility and keep them away from government influence. They had to generate some of their revenues themselves but still needed substantial public financial support—usually half of their total budget—to operate.

To this day, most Canadian nonprofit RTOs have to secure government funding on a recurring basis (every 5 years in the case of INO) and must undergo a government-commissioned assessment of their economic performance. Table 1 lists Canadian RTOs that averaged more than $2 million in total revenues over the 2014–2021 period. Their average net revenues for the same period, except in the case of Alberta Innovates, vary between a $0.04-million loss and a $2.17-million profit. In this period, INO averaged $37.7 million in total revenues, while generating an average of $0.94 million in net revenues. These numbers confirm that, as in the case of INO, Canadian RTOs, whether state-owned or nonprofit, follow a break-even business model.

Several factors were behind INO's creation. In the early 1980s, a report published by the Canadian Association of Physicists stressed the need to establish a research institute in the field of optics and photonics. At the same time, the Canadian government embarked on an effort to redistribute its federal research activities across the country—at the time they were concentrated in the province of Ontario. Branches of the National Research Council of Canada (NRC) were created in different provinces, and it was proposed that an optics institute be set up in Quebec City, which already produced half of Canada's PhDs in this field. The project did not materialize but led instead to the creation of INO through a provincial/federal joint program called the Subsidiary Agreement on Scientific and Technological Development. In 1985, while the INO project was still in gestation, the Quebec government changed its status from a public research center to a private nonprofit organization, with full self-financing as a long-term objective. INO was thus officially incorporated in December 1985 with the official mandate of assisting the growth of the Canadian optics sector through R&D services. From its inception, there was a clear desire to make INO as financially independent as possible, and it was indeed able to generate external revenues, as early as March 1987, from R&D consulting services delivered to small firms and from a research project supported by the Quebec Institute for Research on Occupational Health and Safety, a public organization. While it relied on NRC recommendations to determine its structure and scientific program, INO also contacted several private enterprises to determine its material needs and establish the profile of the researchers it wanted to hire. In addition, INO was able to draw on the expertise of the government-owned Centre de recherche industrielle du Québec, which was located nearby, for recommendations on its structure and organization.

INO's birth also owes much to the individual efforts of Jean-Guy Paquet, who was then the rector of Université Laval, Quebec City's main university. A former professor of electrical engineering, Paquet used his extensive knowledge in the field of optics and his entrepreneurial skills to convince the municipal, provincial and federal levels of government, as well as various public and private partners, to locate INO in Quebec City. More importantly, even before the start of construction, Paquet was behind the idea of moving INO from its initial location on the Université Laval campus to a new site, halfway between Quebec City's international airport and the university, which was seen as a future technology park. Paquet's decision was definitely a major factor in INO's development as a business and industry-oriented organization, albeit with deep scientific and academic roots. INO would undoubtedly have remained focused on applied research if it had stayed on a university campus. Its new location gave it an opportunity to forge close ties with private firms that set up operations near its headquarters and with the optics businesses that it would later spin off. Thus the positioning of INO at the junction of the university, government and industry sectors also led to the gradual formation of a specialized R&D cluster in optics and photonics in the Quebec City region, with the presence, in addition to INO, of the Centre d'optique, photonique et laser (COPL) at Université Laval, the Valcartier Defence Research Establishment, the federal government's NRC Industrial Research Assistance Program, large companies specializing in optics and photonics such as Exfo Inc., as well as venture capital organizations such as Anges Québec (Ouimet et al., 2007).

From its early years of operation, INO was able to take advantage simultaneously of the academic, government and private sectors to launch its R&D as well as its commercial

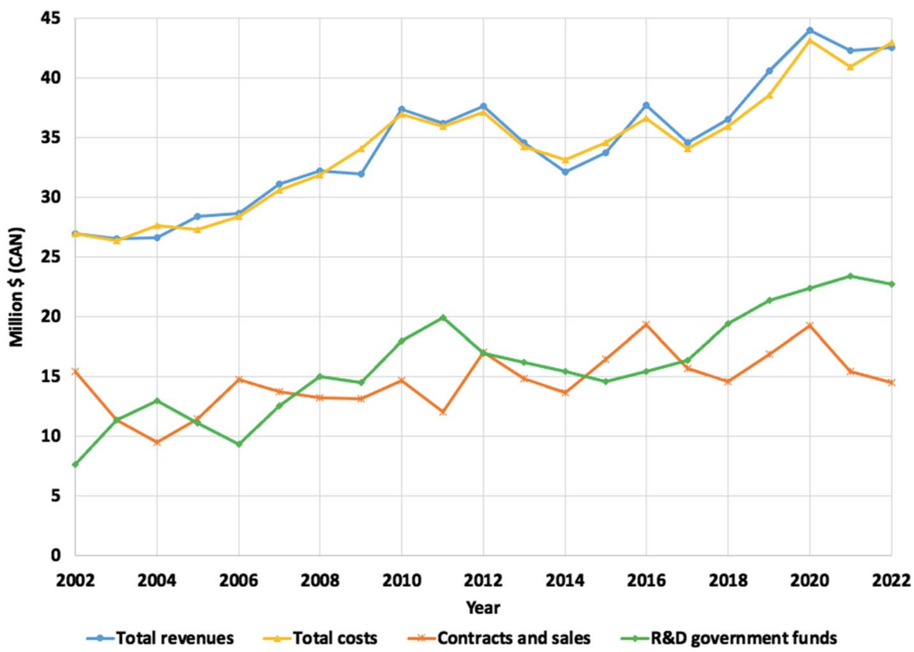

Fig. 1 Evolution of INO's total revenues and expenses. Source: INO annual reports, 2002–2022

activities. The influence of the three sectors was felt first at the governance level. The INO board of directors is mainly composed of representatives of the financial and industrial private sectors. Scientists and engineers dominate another major component of INO's governance structure, its R&D consultative committee, the mission of which is to advise INO on its "strategic scientific orientations with regard to the evolving needs of Canadian businesses." In 2019, this committee was composed of 14 members: 6 from universities and academic institutions, 3 from private companies, 3 from government organizations and 2 from INO. The provincial and federal governments are ex-officio members of INO, along with other affiliate and associate members mainly representing the private sector. Through INO's membership system, both levels of governments can monitor INO's activities on a yearly basis since it allows them to participate in its annual general meetings and approve its financial statements.

As shown in Fig. 1, INO's total revenues have been almost equal to its expenses for the past twenty years, and revenues generated by its industrial contracts and sales more or less match the R&D funding it receives from the provincial and federal governments. These public funds are mainly used by INO to sustain its Internal Research Program (IRP). INO considers the IRP as not only a basic and applied research program but also the cornerstone of its innovation capabilities and entrepreneurship strategies, which are established according to the signals of the most promising optics-photonics markets.

The last government assessment of INO's activities and economic performance, conducted in 2016, estimated that each public dollar invested in the IRP resulted in a $3.90 investment in the same program by other INO industrial partners. Moreover, each dollar invested by government in INO's IRP generated an added value of $1.67 in the Canadian economy (Thiogane, 2016). More generally, INO's R&D planning has incorporated economic and entrepreneurship parameters at least for the last 20 years, resulting in

Table 2 Share of scientific publications of INO in collaboration with universities, government agencies and private enterprises (1988–2021)

Collaborating organization	Share of collaborations		
	1988–98	**1999–2008**	**2009–21**
University	41.9%	44.4%	39.6%
Government	17.8%	25.5%	27.8%
Industry	17.1%	20.1%	15.7%
INO (internal)	36.4%	30.1%	46.0%

such initiatives as its entrepreneur-in-residence program, launched in 2009, and more recently in its spin-off incubator Quantino, created in 2020. Another way for INO to connect research with the market has been to develop strategic R&D alliances and partnership agreements with private companies. For instance, in 2002, INO signed a partnership with the American companies Honeywell and Indigo Systems Corporation to access new technological infrastructures, develop its patent portfolio and increase its sales in imaging applications and infrared detection. A number of similar alliances and partnerships have been developed over the years with Canadian and U.S.-based companies as a means for INO to complete technology transfers or develop and commercialize new products. As explained in the following section, another way for INO to develop relationships with private companies, but also with universities and government agencies, has been through scientific collaborations.

INO's scientific and technological collaborations

Publishing scientific articles in peer-reviewed journals and conference proceedings is not INO's primary mission, but it is implicitly part of its original mandate of "playing a key role in optics development in Canada." Moreover, INO's scientific activity contributes to developing and maintaining "the basic expertise required to maintain the Institute's innovation capability." As stated earlier, the publication of scientific articles by RTOs should not be interpreted as a sign of a disconnect from the market (Zaichenko, 2018). Analyzing their articles can provide useful information on the level of RTOs' interaction with universities, research-oriented government agencies and even private companies. Between 1988 and 2021, INO's scientific workforce published an average of 25 peer-reviewed publications per year for a total of 828 papers accessible through the Google Scholar database (this number does not account for scientific presentations and non-peer-reviewed scientific and technical reports published by INO researchers). INO's scientific activity stands in stark contrast to that of most of the other Canadian RTOs, which seldom publish, if at all. A detailed analysis of INO's publications also provides more evidence of its pivotal position between academic and industrial research as well as between the public and private sectors. Table 2 shows that for the three last decades, universities have unsurprisingly been INO's main scientific collaborators. Indeed, 39.6–44.4% of INO's publications have involved at least one university as a collaborator. Université Laval, with which INO has historical ties and from which it hires many of its engineers and scientists, is its primary scientific collaborator.

Table 3 INO's top 10 scientific collaborators, 1988–2021

Rank	Organization	Type
1	Université Laval	University
2	Defence Research and Development Canada	Government agency
3	Canadian Space Agency	Government agency
4	Université de Montréal	University
5	National Research Council Canada	Government agency
6	European Space Agency	Government agency
7	University of Toronto	University
8	University of Waterloo	University
9	ImmerVision Inc	Private enterprise
10	Japan Aerospace Exploration Agency	Government agency

Interestingly, the share of research published solely by INO researchers increased from 36.4% in the 1988–98 period to 46% in the 2009–21 period, indicating that, with an expanding scientific workforce, INO has over time become less dependent on universities for its in-house research projects. While the share of INO's scientific collaborations with private companies, which has varied from 15.7% to 20.1% over the last three decades, may seem low in comparison to its collaborations with universities and government agencies, it is nonetheless much higher than the average share of Canadian universities' scientific collaborations with industry, which is lower than 3% (Lebeau et al., 2008). It is also noteworthy that most of the private companies that collaborate scientifically with INO are also clients or business partners of the institute, and 20% of them are either companies to which INO has transferred technologies or companies that INO has itself spun off. This again indicates a positive relationship between, on the one hand, the production of basic and applied knowledge through scientific publications and, on the other, RTO entrepreneurship.

Finally, the proportion of INO's scientific collaborations with government agencies has grown significantly, from 17.8% to 27.8% since the institute's inception, thanks especially to the increase in projects with national space agencies in Canada, Europe, Japan and Argentina. As shown in Table 3, Canadian and international government agencies are, along with Canadian universities, the organizations with which INO collaborates the most in scientific research. Among the most frequent co-authors of scientific articles published by INO scientists are researchers from the Canadian Space Agency, the European Space Agency and the Japan Aerospace Exploration Agency. Usually, international scientific collaborations with these types of agencies also involve commercial R&D contracts. According to INO, research collaborations with the Canadian Space Agency and Defence Research and Development Canada have enabled it to increase its revenues from industrial clients in the aerospace, defense and security sectors. While prestigious collaborations with national space agencies are not the ones expected to generate the highest revenues for INO, they nevertheless have considerable symbolic value since they are tangible proof of INO's, and by extension Quebec's and Canada's, technological excellence on the international scene. INO uses this symbolic capital when renegotiating its public funding with the federal and provincial governments and as a showcase to attract new industrial contracts with private companies. For instance, in 2012, INO

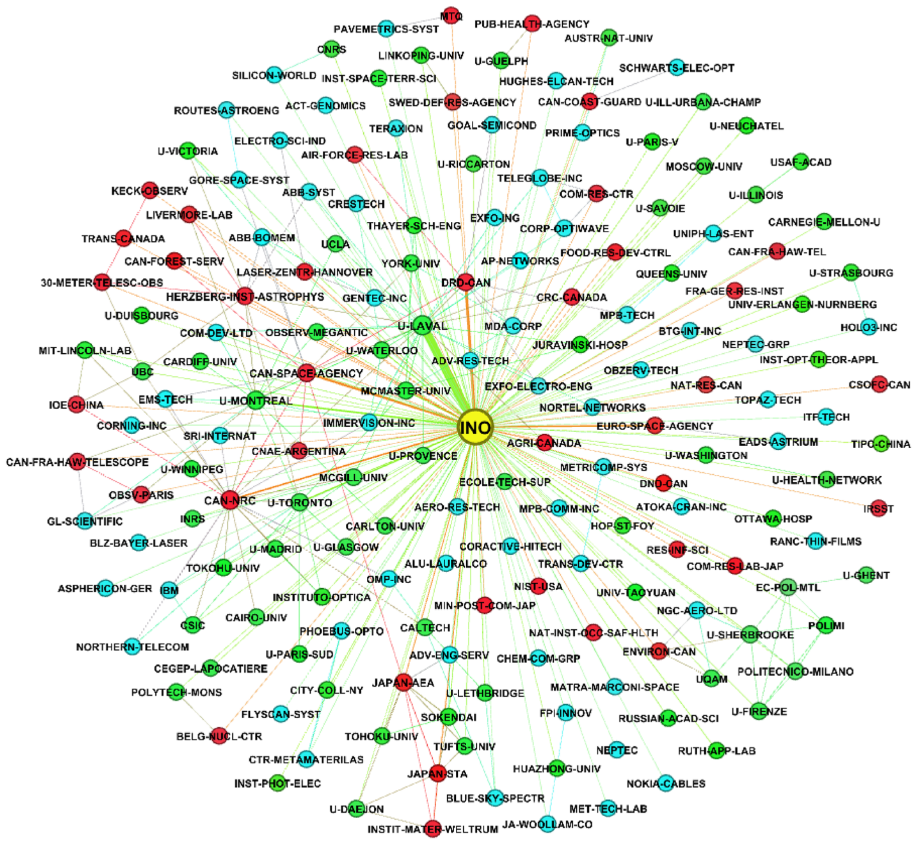

Fig. 2 INO's network of scientific collaborations

organized an important public relations event with Canada's minister of Industry, Christian Paradis, and Steve MacLean, president of the Canadian Space Agency, to announce the launch a medical diagnosis technology called MicroFlow, which was used on the International Space Station a year later.

Figure 2 shows the global network of INO's scientific collaborations between 1988 and 2021. Each link between INO and another organization represents a collaboration on a scientific research paper. Organizations represented by green nodes are universities, those represented by red nodes are government agencies, and those represented by blue nodes are private enterprises. Several organizations, including INO, can collaborate on a single paper and thus be connected to each other. This visual representation further demonstrates the status of INO as a pivotal organization, illustrating the diversity of its scientific collaborations with a variety of institutional partners from the academic, government and industrial sectors.

INO's entrepreneurship: R&D services, patenting, technology transfers and spin-offs

INO's main sources of revenue, excluding government funding, are three types of activity: R&D contracts in response to short to mid-term market demand from private companies or government agencies; sales of products defined BY INO as "marketable prototypes whose potential INO wants to evaluate before transferring the technology or highly specialized products which have a limited market and high

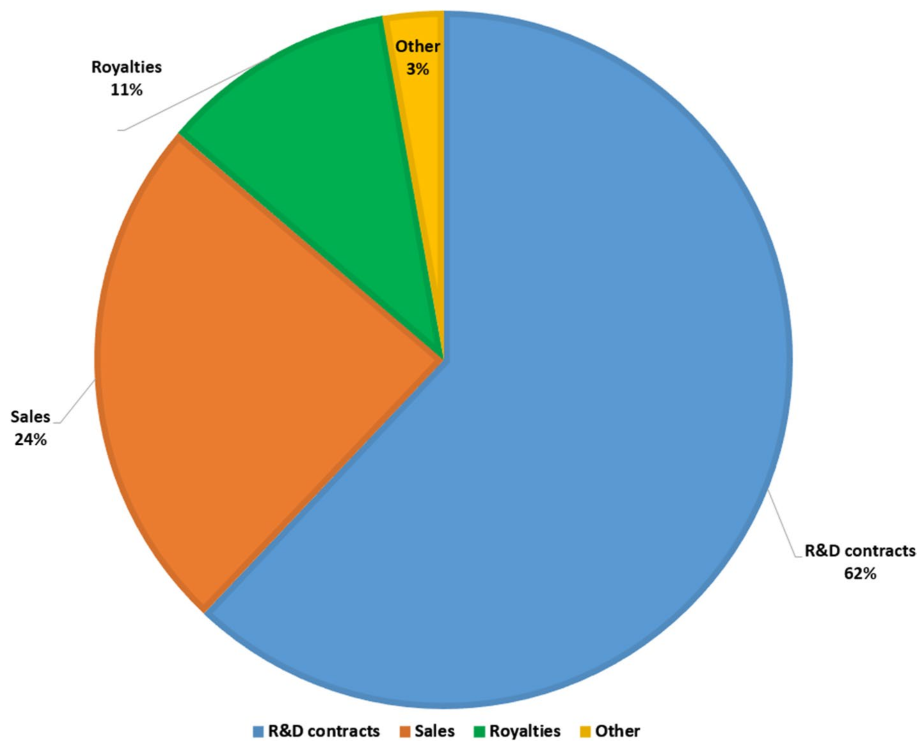

Fig. 3 Sources of INO's external revenues (2011–2016). Source: INO annual reports, 2011–2016

added value"; and royalties that may stem from technologies developed by INO and licensed to Canadian manufacturers or from spin-off companies that manufacture and sell products developed by INO researchers. While the data was not accessible for the most recent period, between 2011 and 2016, R&D contracts, product sales and royalties accounted respectively for 62%, 24% and 11% of INO's total commercial revenues (Fig. 3). Between 2010 and 2021, commercial revenues came mainly from Canada (65.4%), which is not surprising since INO's regular revenues come mainly from delivering R&D services to Canadian SMEs. the United States (14.6%), Asia (12.4%), and Europe (7.3%) were the other regions where revenues were generated. Since 2010, Asia (especially China and Japan) is where INO has been trying to develop more business opportunities, as reflected in the eight technology transfers it has completed on that continent. INO's exploration of Asian markets is also consistent with a general trend toward the internationalization of RTOs' commercial activities (Berger & Hofer, 2011).

INO has also understood that its market would be too small if it limited its client base to companies that only use optics and photonics technologies as their core business. It has thus launched a client diversification strategy and developed commercial ties with companies that specialize in other industrial sectors but still use optics and photonics technologies. This is reflected in the distribution of INO's commercial revenues by industrial sector. Between 2009 and 2019, the optics and photonics sector accounted for only 18% of INO's commercial revenues. Defense and public security represented 20.5%, followed by the transport industry (18%), aerospace (13.5%), industrial processes (12.5%), health and life sciences (11%), and other industries (5.5%).

The 1990s, INO's first full decade of operation, were particularly critical for its growth as a commercially oriented organization. Between 1993 and 2002, its sales increased from approximately \$1.5 million to \$8 million, its R&D contracts went up from \$3 million to \$7.5 million, and the number of INO employees rose from 120 to 240. During the same decade, 37.5% of the value of INO's R&D contracts came from the federal government's Department of Public Works and Government Services. One quarter of these government contracts were with the Canadian Space Agency and one third with the Defencc Research Establishment in Valcartier, which has its headquarters in the Quebec City metropolitan area. Interestingly, in the 2010s, government contracts accounted for only 14.6% of all INO's R&D contracts, while SMEs accounted for 61%, large companies 18%, and universities 6.4%. The decline in government contracts and the concomitant growth of private industry contracts again show the importance of INO's relationships with a variety of actors. Indeed, in the early days of INO's operations, when there were fewer private industry clients, it was able to rely on government contracts to grow and take the time needed to develop business relationships and partnerships with private companies. In other words, the Canadian government, through its agencies, created demand for INO's services and enabled it to maintain operations until private organizations entered the scene. After the 1990s, relying on government contracts was less important since private industry clients were available and ready to make use of INO's R&D and commercial services.

While R&D contracts and services remain INO's main sources of of revenue, the activities that the organization values and publicizes the most are the creation of spin-off companies and technology transfers. They both involve a high degree of uncertainty and require several years of planning, investment and laboratory work, as opposed to R&D contracts and technical services, which can be carried out in a matter of weeks or months. For instance, in the early 1990s, INO struck a partnership with the Quebec Ministry of Transport to develop an instrument for automatically detecting and measuring road ruts. This partnership resulted in the development of a *rutometer*, which INO enhanced in the 2000s to include a high-resolution imagery system. Both systems were later integrated in a single laser apparatus, which was then commercialized in 2009 by INO through a spin-off called Pavemetrics. This example illustrates the importance of INO's positioning between public and private sector organizations, since the technology behind the private spin-off resulted from the adaptation and improvement of a technology that was initially developed for a government agency. It also highlights the importance of long-term R&D planning and development to INO for reaching its entrepreneurship goals. Technological innovation trajectories are winding and uncertain (Rosenberg, 1996), and it is thus crucial for an institution such as INO to rely on the renewed financial support of the government to pursue such risky projects without jeopardizing the financial equilibrium of the whole organization.

Prototype sales took off in the 1990s but were not necessarily motivated by profit seeking. The main goal was "to evaluate market interest in certain products INO [had] developed to the commercial prototype before reaching technology transfer agreements with Canadian businesses" (INO, 2003). In other words, INO's strategy consisted in using these sales primarily to test the Canadian and U.S. markets. If the technologies were deemed to have economic potential, they could be sold to another company through

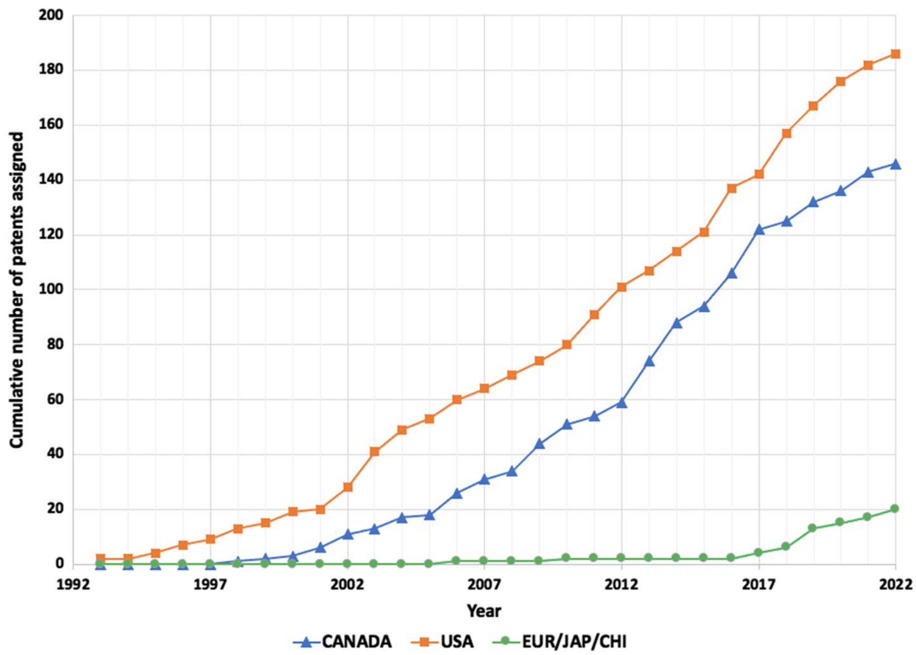

Fig. 4 Cumulative number of INO's assigned patents (1992–2022). Source: INO's website (https://www.ino.ca/en/resources/patents/)

a spin-off company, a technology transfer or some other means. Since the number of Canadian companies with an international reach in the photonics sector was small, it is reasonable to assume that creating spin-off companies was initially a necessity for INO. The RTO had to create the companies to which it could transfer its technologies, since these companies simply did not exist in Quebec or elsewhere in Canada. INO spin-off companies are also based on the portfolio of technologies developed and held by the RTO through its 325 patents. For instance, Fiso Technologies, a 1994 INO spin-off, commercializes optical fibers based on the Fabry–Perot principle, a technology initially developed by INO and protected by one of its U.S. patents. As shown in Fig. 4, INO patents its technologies mostly in the U.S., which is the main market for its spin-offs. A significant share of these patents is dyadic, with assignments in both Canada and the United States. Eager to diversify its international markets, INO has also been patenting its technologies in Europe, China and Japan since 2017. In addition, spin-offs are used by INO to market its technologies through licensing agreements as part of its mission to foster the growth of young companies in the optics industry. One of the first examples of such a strategy was the commercialization of an optical components modeling software system called BPM_CAD. In the early 1990s, INO produced and sold the system in a dozen countries, before launching a spin-off, Optiwave, in 1994 to take over these activities. Since its inception, Optiwave has licensed its software in over 70 countries. The company now employs 200 people and generates yearly revenues of $10 million.

Other more recent spin-offs, such as RaySecur, Handyem and Optosecurity, rely on technologies previously owned by INO through patenting. In other words, technology transfers leading to the creation of businesses are developed several years earlier and largely benefit from INO's Internal Research Program, which is primarily

Table 4 INO's top 15 spin-offs in terms of revenues generated in 2021

Spin-off	Year created	Location	Employees	Total revenues ($M)	Patents owned
Optel Vision	1992	Quebec City	400	67	1
LeddarTech	2007	Quebec City	171	40	21
TeraXion	2000	Quebec City	190	32	74
OpSens	2004	Quebec City	140	20	17
OptoSecurity	2004	Quebec City	45	20	35
Fiso Technologies	1994	Quebec City	63	12	8
Optiwave	1994	Ottawa	200	10	-
Obzerv Inc	2002	Quebec City	50	9	2
Doric Lenses	2004	Quebec City	45	8	2
Pavemetrics	2009	Quebec City	45	8	3
P&P Optica	1995	Waterloo	41	8	-
CorActive	1998	Quebec City	30	7.7	-
Handyem	2011	Quebec City	31	6	4
DxBioTech	2017	Montreal	31	6	1
PyroPhotonics	2004	Montreal	20	4.5	20

Table 5 Breakdown of INO spin-offs and technology transfers by geographical area

Location	Quebec City	Rest of Quebec	Rest of Canada	International	Total
Spin-offs	22	7	5	1	35
Technology transfers	26	23	12	13	74

government-funded. This confirms Arnold et al.'s observation that RTOs rely on public funds "to move a little ahead of market needs, familiarizing themselves with new technological opportunities through research projects" (Arnold et al., 1998). While spin-offs and technology transfers are more difficult to bring about than the more routinized R&D contracts, they are considered more rewarding in terms of the return on federal and provincial government investments in INO's research capabilities. Indeed, these activities usually help to create high-paying jobs and increase Canada's exports of high-technology goods, since most of INO's spin-offs and technology transfers go to companies that generate more than 90% of their revenues abroad, especially in the United States.

Table 4 shows INO's top 15 spin-offs in terms of revenues generated in 2021. All but four are based in the Quebec City area, and most of them are R&D-intensive, as shown by the number of patents they own. In 30 years of activity, INO has achieved 35 spin-offs and 74 technology transfers (Table 5). Out of 35 spin-offs, 22 (64%) companies are located in Quebec City, within 15 km from INO headquarters. They are thus a major part of Quebec City's technology park and specialized regional system of innovation in optics and photonics, with INO as a core component and driver of growth and transformation. INO's technology transfers have a similar geographical characteristic, with 26 out of 74 (35%) being made to companies within a 15-km distance from INO. There is also an obvious relationship between INO's technology transfers and its spin-offs, since technology transfers are also a means of generating new spin-offs. In the case of INO, almost one third (24) of its technology transfers have been used to create a spin-off. After developing financially and growing in size, these spin-offs, especially the ones located in Quebec City's technology park, keep close ties with INO through R&D partnerships and commercial contracts and benefit from knowledge spillovers from the RTO.

Finally, another important factor to consider when analyzing INO's entrepreneurship performance is the fact that 55% of INO's spin-offs were founded by a former INO scientist or engineer. In most cases, the technology on which the spin-off is based was initially developed by an INO R&D team of which the future founder was a member. This shows that INO provides an environment that is conducive to its engineers and scientists becoming entrepreneurs, and its approach bears comparison with the recent program that the Fraunhofer–Gesellschaft has developed to encourage the creation of spin-offs by stimulating entrepreneurship primarily amongst its scientific workforce (Lambertus et al., 2019). Encouraging in-house entrepreneurship remained informal at INO until 2009, when an entrepreneur-in-residence program was launched along with annual innovation awards to encourage and recognize employee creativity and expertise. The entrepreneur-in-residence program was renewed in 2015 with the financial support of the City of Quebec and the Anges Québec investor network. It aims at opening the doors of INO laboratories and portfolios of technologies to entrepreneurs inside or outside the organization who could benefit from its infrastructures and financial support for a period of 12–18 months.

Conclusions

The main use that has been made of RTOs aligns with their traditional role as R&D service providers to SMEs and the concept of "intermediary organization". However, the case of INO suggests that RTOs may also be used by governments as instruments of entrepreneurship. Indeed, in addition to providing services to Canadian SMEs through R&D contracts, one of INO's main features that sets it apart from other Canadian RTOs is its innovation capabilities, which are reflected in its spin-offs and technology transfers. The case offers insights into the conditions that enable RTOs to be entrepreneurial.

First, RTOs that must generate some of their revenues independently of government support may become more market-oriented and more likely to develop an entrepreneurial culture. INO's nonprofit organization status at the intersection of the public and private sectors also gives it the necessary flexibility to engage in long-term, financially and technologically risky projects usually carried out by government-owned laboratories, while exhibiting an entrepreneurial and business-oriented culture more often associated with private sector behavior. In this regard, INO could be characterized as a "multi-sphere" organization, i.e., an organization that operates "at the intersection of the university, industry and government institutional spheres and synthetize[s] elements of each sphere in their institutional design" (Ranga & Etzkowitz, 2013, p. 244). Second, the INO case shows that strong and renewed government funding is required for entrepreneurial RTOs to build the research infrastructure and workforce that will enable them to develop innovative products and services. In this regard, INO's Internal Research Program not only provides opportunities to conduct mid-to-long-term R&D projects but also an environment in which INO's scientists and engineers can bring their inventions to the commercial stage.

Third, the INO case highlights the importance of long-term R&D planning, incorporating commercial strategies and goals, for the development of patent portfolios and the targeting of specific technological sectors. The relationship between R&D strategic planning and entrepreneurship is illustrated by the significant proportion of INO spin-offs resulting from technology transfers. Finally, perhaps the most important condition for entrepreneurship suggested by the INO case is the RTO's ability to develop multiple and diversified relationships, including scientific collaborations, R&D alliances, and commercial and licensing agreements. By positioning itself at the center of a network of academic, government and private sector institutions, INO has succeeded in shaping and being the engine of a specialized regional system of innovation from which it can draw intellectual and financial resources to develop entrepreneurial activities (Ouimet et al., 2007).

As shown in this paper, the entrepreneurial dimension of an RTO is not necessarily at odds with its more research-based or service-based activities (Gullbrandsen, 2011). The INO case shows, on the contrary, that entrepreneurship can complement basic and applied research and/or the provision of R&D services to SMEs, since the collaborations and partnerships developed through these activities can be used to facilitate and stimulate entrepreneurship. Ultimately, the entrepreneurship of RTOs should be seen as a means of enhancing the market potential of public research. In short, the value of incorporating an entrepreneurship mission in an RTO such as INO does not lie in maximizing its revenues and profits but in building a regional innovation cluster in which the RTO is a driving force. In this regard, RTOs such as INO could be viewed as exemplary instruments of an "entrepreneurial State" that creates and shapes markets through "a highly networked system of actors harnessing the best of the private sector for the national good over a medium-to-long-term horizon" (Mazzucato, 2013, p. 27).

Abbreviations

COPL	Centre d'optique, photonique et laser (Optics, Photonics and Laser Center)
EARTO	European Association of Research and Technology Organizations
INO	Institut National d'Optique (National Optics Institute)
IRP	Internal research program
RTO	Research and technology organization
R&D	Research and development
SME	Small and medium enterprise

Acknowledgements
Not applicable.

Author contributions
Both authors contributed to the research design of this study. MK collected the data. Both authors equally contributed to writing the manuscript.

Funding
No funding has been received by the authors for this research.

Availability of data and materials
Not applicable.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 15 November 2022 Accepted: 11 August 2023
Published online: 30 August 2023

References
Adams, J. D., Chiang, E. P., & Jensen, J. L. (2003). The influence of federal laboratory R&D on industrial research. *Review of Economics and Statistics, 85*(4), 1003–1020.
Arnold, E., Rush, H., Bessant, J., & Hobday, M. (1998). Strategic planning in research and technology institutes. *R&D Management, 28*(2), 89–100.
Aucoin, P. (1995). *The New Public Management: Canada in Comparative Perspective*. Institute for Research on Public Policy.
Barge-Gil, A., & Modrego, A. (2011). The impact of research and technology organizations on firm competitiveness. Measurement and determinants. *Journal of Technology Transfer, 36*, 61–83.
Berger, M., & Hofer, R. (2011). The internationalisation of research and technology organisations (RTOs)—Conceptual notions and illustrative examples from European RTOs in China. *Science, Technology & Society, 16*(1), 99–122.
Bienkowska, D., Larsen, K., & Sörlin, S. (2010). Public-private innovation: Mediating roles and ICT niches of industrial research institutes. *Innovation: Management Policy & Practice, 12*, 206–216.
Bozeman, B., & Crow, M. (1990). The Environments of U.S. R&D laboratories: Political and market influences author(s). *Policy Sciences, 23*(1), 25–56.
Breznitz, D., Ornston, D., & Samford, S. (2018). Mission critical: The ends, means, and design of innovation agencies. *Industrial and Corporate Change, 27*(5), 883–896.
Brown, R., & Mason, C. (2014). Inside the high-tech black box: A critique of technology entrepreneurship policy. *Technovation, 34*(12), 773–784.
Carayannis, E. G., Rogers, E. M., Kurihara, K., & Allbriton, M. M. (1998). High-Technology spin-offs from government R&D laboratories and research universities. *Technovation, 18*(1), 1–11.
Chandrasekaran, A., Linderman, K., & Schroeder, R. (2012). Antecedents to ambidexterity competency in high technology organizations. *Journal of Operations Management, 30*(1–2), 134–151.
Charles, D., & Stancova, K., et al. (2016). Entrepreneurial discovery process and research and technology organisations. In K. Dimitrios (Ed.), *Governing Smart Specialisation* (pp. 80–94). Routledge.
Comacchio, A., Bonesso, S., & Pizzi, C. (2012). Boundary spanning between industry and university: The role of technology transfer centres. *Journal of Technology Transfer, 37*, 943–966.
Comin, D., Licht, G., Pellens, M., & Schubert, T. (2018). Do companies benefit from public research organizations? The impact of the Fraunhofer Society in Germany. *Papers in Innovation Studies No. 2018/7*, Center for Innovation, Research and Competences in the Learning Economy, Lund University. https://www.fraunhofer.de/content/dam/zv/de/leistungsangebot/wirkung-von-forschung/the-impact-of-fraunhofer.pdf
Cruz-Castro, L., Martinez, C., Penasco, C., & Sanz-Menéndez, L. (2020). The classification of public research organizations: Taxonomical explorations. *Research Evaluation, 29*(4), 377–391.
David, P., Hall, B., & Toole, A. (2000). Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. *Research Policy, 29*(4–5), 497–529.
De la Torre, E. M., Ghorbankhani, M., Rossi, F., & Sagarra, M. (2021). Knowledge transfer profiles of public research organisations: The role of fields of knowledge specialization. *Science and Public Policy, 48*(6), 860–876.
De Silva, M., Howells, J., & Meyer, M. (2019). Innovation intermediaries and collaboration: Knowledge-based practices and internal value creation. *Research Policy, 47*(1), 70–87.
Di Gregorio, D., & Shane, S. (2003). Why do some universities generate more start-ups than others? *Research Policy, 32*(2), 209–227.
Etzkowitz, H., Webster, A., & Healy, P. (1998). *Capitalizing Knowledge: New Intersections of Industry and Academia* (p. 1998). State University of New York Press.
European Association for Research and Technology Organizations. (2007). *Research and Technology Organisations in the Evolving European Research Area*.
Feldman, M. P., & Kelly, M. (2006). The *ex ante* assessment of knowledge spillovers: Government R&D policy, economic incentives and private firm behavior. *Research Policy, 35*(10), 1509–1521.
Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry, 12*(2), 219–245.
Flyvbjerg, B. (2011). Case study. In N. K. Denzin & Y. S. Lincoln (Eds.), *The sage handbook of qualitative research* (pp. 301–316). Sage.
Fortin, L. (1985). La Politique Technologique Québécoise. *Politique, 8*, 23–44.
Giannopoulou, E., Barlatier, P. J., & Pénin, J. (2019). Same but different? Research and technology organizations, universities and the innovation activities of firms. *Research Policy, 48*(1), 223–233.
Giannopoulou, E., Gryszkiewicz, L., & Barlatier, P. J. (2011). A conceptual model for the development of service innovation capabilities in research and technology organisations. *International Journal of Knowledge Management Studies, 4*(4), 319–335.
Godin, B., & Trépanier, M. (1995). La politique scientifique et technologique québécoise: La mise en place d'un nouveau système national d'innovation. *Recherches Sociographiques, 36*(3), 445–477.
Gonzalez, X., & Pazo, C. (2008). Do public subsidies stimulate private R&D spending? *Research Policy, 37*(3), 371–389.
Gullbrandsen, M. (2011). Research institutes as hybrid organizations: Central challenges to their legitimacy. *Policy Sciences, 44*, 215–230.
Harrison, R., & Leitch, C. (2010). Voodoo institution or entrepreneurial university? Spin-off companies, the entrepreneurial system and regional development in the UK. *Regional Studies, 44*(9), 1241–1262.

Hecklau, F., Kidschun, F., Kohl, H., & Tominaj, S. (2020). Analyzing the role of research and technology organizations (RTOs) in national innovation systems (NIS). In P. Griffith (Ed.), *Proceedings of 16th European Conference on Management Leadership and Governance* (pp. 95–105). Academic Conferences Ltd.

Howells, J. (2006). Intermediation and the role of intermediaries in innovation. *Research Policy, 35*, 715–728.

INO (Institut National d'Optique). (2003). *Vision* 2003. Sainte-Foy

Intarakumnerd, P., & Goto, A. (2018). Role of public research institutes in national innovation systems in industrialized countries: The cases of Fraunhofer, NIST, CSIRO, AIST, and ITRI. *Research Policy, 47*(7), 1309–1320.

Lambertus, T., Schmalenberg, J., & Keckl, M. (2019). *Case study on programmes to promote spin-offs at Fraunhofer-Gesellschaft,* Contribution to the OECD TIP Knowledge Transfer and Policies Project. https://stip.oecd.org/assets/TKKT/CaseStudies/16.pdf

Landry, R., Amara, N., Cloutier, J. S., & Halilem, N. (2013). Technology transfer organizations: Services and business models. *Technovation, 33*(12), 431–449.

Lebeau, L. M., Laframboise, M. C., Larivière, V., & Gingras, Y. (2008). The effect of university–industry collaboration on the scientific impact of publications: The Canadian case, 1980–2005. *Research Evaluation, 17*(3), 227–232.

Lecluyse, L., Knockaert, M., & Spithoven, A. (2019). The contribution of science parks: A literature review and future research agenda. *Journal of Technology Transfer, 44*, 559–595.

Leyden, D. P., & Link, A. (2015). *Public Sector Entrepreneurship. U.S. Technology and Innovation Policy*. Oxford University Press.

Martinez-Vela, C. (2016). *Benchmarking Research and Technology Organizations (RTOs): A comparative analysis*. MIT-IPC Working Paper 16–005. https://ipc-dev.mit.edu/sites/default/files/2019-01/16-005.pdf

Mathisen, M., & Rasmussen, E. (2019). The development, growth, and performance of university spin-offs: A critical review. *Journal of Technology Transfer, 44*, 1891–1938.

Mazzucato, M. (2013). *The entrepreneurial state: Debunking public vs. private sectors myths*. Anthem Press.

Miller, K., Alexander, A., & Cunningham, J. A. (2018). Entrepreneurial academics and academic entrepreneurs: a systematic literature review. *International Journal of Technology Management, 77*(1-2–3), 9–37.

Mortazavi, R. S., Mehrabanfar, E., Banaitis, A., & Banaitiene, N. (2016). Framework for assessing technological innovation capability in research and technology organizations. *Journal of Business Economics and Management, 17*(6), 825–847.

Ouimet, M., Landry, R., & Amara, N. (2007). Network positions and efforts to innovate in a small Canadian optics and photonics cluster. *International Journal of Entrepreneurship and Innovation Management, 7*, 251–271.

Ranga, M., & Etzkowitz, H. (2013). Triple helix systems: An analytical framework for innovation policy and practice in the knowledge society. *Industry and Higher Education, 27*(3), 237–262.

Readman, J., Bessant, J., Neely, A., & Twigg, D. (2018). Positioning UK research and technology organizations as outward-facing technology-bases. *R&D Management, 48*(1), 109–120.

Rincon, D. C., & Albors Garrigos, J. (2017). Research and technology organizations' mobilizers of the regional environment: Competitive strategies. *European Journal of Management and Business Economics, 26*(2), 180–198.

Rosenberg, N. (1996). Uncertainty and technological change. In R. Landau, T. Taylor, & G. Wright (Eds.), *The Mosaic of Economic Growth* (pp. 334–335). Stanford University Press.

Rothaermel, F., Agung, S., & Jiang, L. (2007). University entrepreneurship: A taxonomy of the literature. *Industrial and Corporate Change, 16*(4), 691–791.

Shane, S. A. (2004). *Academic Entrepreneurship: University Spin-offs and Wealth Creation*. Edward Elgar.

Sharif, N., & Baark, E. (2011). The Transformation of Research Technology Organisations (RTOs) in Asia and Europe. *Science, Technology and Society, 16*(1), 1–10.

Siegel, D., & Wright, M. (2015). University technology transfer offices, licensing, and start-ups. In A. Link, D. Siegel, & W. Mike (Eds.), *Chicago handbook of university technology transfer and academic entrepreneurship* (pp. 1–40). University of Chicago Press.

Sjöö, K., & Hellström, T. (2019). University–industry collaboration: A literature review and synthesis. *Industry and Higher Education, 33*(4), 275–285.

Suominen, A., Kauppinen, H., & Hyytinen, K. (2021). 'Gold', 'Ribbon' or 'Puzzle': What motivates researchers to work in Research and Technology Organizations. *Technological Forecasting and Social Change, 170*, 120882.

Tann, J., Platts, A., & Stein, J. (2004). The Roles of independent research and technology organizations in the United Kingdom's technology transfer mechanism to SMEs. *Technology Analysis & Strategic Management, 14*(2), 241–249.

Taverdet-Popiolek, N. (2022). Economic footprint of a large French Research and Technology Organisation in Europe: Deciphering a simplified model and appraising the results. *Journal of the Knowledge Economy, 13*(1), 44–69.

Thiogane, I. (2016). Institut National d'Optique (INO): Rapport d'évaluation pour la période du 1er avril 2010 au 31 mars 2016. https://numerique.banq.qc.ca/patrimoine/details/52327/3291589

Wright, M., Birley, S., & Mosey, S. (2004). Entrepreneurship and university technology Transfer. *Journal of Technology Transfer, 29*, 235–246.

Xue, J., & Klein, P. G. (2010). Regional determinants of technology entrepreneurship. *International Journal of Entrepreneurial Venturing, 1*(3), 291–308.

Zaichenko, S. (2018). The human resource dimension of science-based technology transfer: Lessons from Russian RTOs and innovative enterprises. *Journal of Technology Transfer, 43*, 368–388.

Publisher's Note