Challenges and Opportunities for Canadian Deep Tech Commercialization

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Key messages:

- Deep tech is characterized by long lead times and significant uncertainty but has the potential to deliver important results
- Intellectual property retention is key to creating domestic economic benefits from deep tech breakthroughs
- Risk-tolerant public funds are needed to support deep tech commercialization, particularly in the pre-revenue phase
- Canada can learn from international practices, particularly those from the U.S. and Israel
- Weaknesses in data collection are hindering domestic progress

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Abstract

This work reviews the current state of Canadian deep tech commercialization efforts, focusing on suggesting practical solutions to challenges to translating research into disruptive technological innovation beyond the lab. The report finds consensus both in the literature and in practical examples of the American and Israeli approach to deep tech commercialization regarding the importance of risk-tolerant public funding focused on small businesses to bridge the "valley of death" for deep tech, with a particular emphasis on spinouts from universities that involve inventors. In making recommendations for policy reform based on approaches that have worked elsewhere, this work stresses the importance of considering contextual differences that requires evidence-based adaptation of these programs if they are to work in Canada and identifies clear weaknesses in Canadian data collection that hinder related policy development. The report concludes with an overview of Canadian deep tech in three sectors: artificial intelligence (AI), cleantech, and quantum technologies, and makes recommendations for next steps to secure value for Canada in each of these sectors that are readily generalizable to other deep tech sectors. These recommendations are centered around removing barriers to accessing support and navigating regulatory complexities for small firms, improved data collection and tracking with respect to university spinout and deep tech startup outcomes, and careful policy development focused on balancing IP retention and value extraction against the need for foreign direct investment.

Introduction

Deep tech as a concept is difficult to pin down. A recent review provides the most comprehensive overview and constructs a working definition by synthesizing common elements that link disparate definitions provided in references therein, concluding that deep tech is "Early-stage technologies based on scientific or engineering advances, requiring long development times, systemic integration, and sophisticated knowledge to create downstream offerings with the potential to address grand societal challenges." (Romasanta, Ahmadova, Wareham, & Priego, 2021). This review also identifies twenty technology sectors most often associated with deep tech, including the three example sectors discussed later, and provides a set of characteristics that distinguish deep tech from "shallow" tech.

Unpacking this definition, deep tech is not a tech sector unto itself; rather, it is the subset of many tech sectors that remains technically unproven while having a clear value proposition. Unlike "shallow" tech that is gated primarily by market risk, deep tech is gated primarily by technical risk, hence the requirement for "long development times, systemic integration, and sophisticated knowledge". The research necessary to advance deep tech results in generation of intellectual property (IP) as technical hurdles are overcome, rewarding those engaged with a defensible moat and favoring the first mover to a greater degree than other technology classes. These activities are all capital intensive at a stage where commercial revenue is unlikely and has a long path to return on investment (Park, Goudarzi, Yaghmaie, Jon Thomas, & Maine, 2024). This makes traditional means of investment poorly suited to support deep tech in many sectors, with a variety of novel mechanisms arising to address the gap (Barbour & Oldford, 2022; Briggs, 2024b; Lerner & Nanda, 2020; Malek, Maine, & Mccarthy, 2012; Nedayvoda, Delavelle, So, Graf, & Taupin, 2021; Udwin, 2015). On the other hand, deep tech has potential for high returns through the "potential to address grand societal challenges" for those sufficiently patient and risk tolerant (Letta, 2024; Romasanta et al., 2021). Deep tech follows a distribution of value in which a majority of the value creation arises from a minority of technologies, and for which value capture requires investment before the distinction is clarified by the market, similar to venture capital generally (Mallaby, 2022). Because deep tech can represent a step change in technological capabilities and is often dual use, this class of technologies presents key issues for both economic and national security, with security implications made particularly challenging by the fact that it is not always possible to predict all uses of deep tech before it has been fully developed (Brenneis, 2024; Krelina, 2021; World Health Organization, 2021). Finally, the definition is transitory in its application to a particular technology. Once a technology has been developed past the point of technical uncertainty and the market has been clarified, is it no longer "deep" tech.

Innovation is not synonymous with invention (Breznitz, 2021). Where deep tech is concerned, however, innovation and invention go hand in hand. As such, it is the view of the author that any discussion of deep tech is inseparable from a discussion of the associated IP. This should not be construed as an implication that later stages of innovation are unimportant for Canada, for example through adoption of existing technologies or restructuring of existing markets. These are simply beyond the scope of this work.

As such, bringing deep tech to market and securing the advantage of having done so requires care with respect to long term control over IP, especially in a small, open economy such as Canada's (Matthews & Rice, 2022). Canada is effective at producing IP from research but struggles to retain and translate it into economic activity (Bouchard et al., 2023; Cockburn, Macgarvie, & Mckeon, 2023; Gama Dias, Horn, Mercado-Lara, Mokaya, & Provencher, 2020; Government of Canada, 2011; Hinton, Witzel, & Wajda, 2023; Matthews & Rice, 2022). As the value of the world's leading companies has shifted from tangible to intangible assets, Canada has made no significant changes to its strategy with respect to intangible assets and has stagnated economically (Breznitz, 2021; Ciuriak & Carbonneau, 2024; Cockburn et al., 2023; Deacon et al., 2023). Recent studies suggest that the IP that is the output of Canada's post-secondary research institutions represents a key input to the innovation pipeline that is currently going underutilized as control over a large proportion of IP arising from post-secondary institutions is lost to Canada before any attempt at value extraction can be made (Hinton et al., 2023; Matthews & Rice, 2022; Park, Goudarzi, et al., 2024; Park, Maine, et al., 2024). This work attempts to elucidate the issues at play and suggests realistic means by which to address them.

Challenges

Post-secondary IP Governance

Many deep tech projects have their root in academia (Hinton et al., 2023; Matthews & Rice, 2022; Park, Goudarzi, et al., 2024; Park, Maine, et al., 2024). The importance of careful governance of IP arising from publicly funded research was recognized in the United States in 1980 through the Bayh-Dole Act. This legislative framework gives the option to publicly funded research institutions to take ownership of IP generated through taxpayer funding, subject to several conditions. In the case of post-secondary research, these conditions include but are not limited to pursuit of patent protection, requiring that exclusive licensing ensure that the resulting products are manufactured substantially domestically, and favoring small businesses as licensees (Smith, 2023). Failure to comply gives the government "march-in rights" to take control over the IP in question, rights that have not needed to be exercised to date (Hickey & Blevins, 2024). While the Bayh-Dole act does not mandate institutional ownership of research IP, today almost every major research institution in the United States elects to take ownership, licensing the IP through a technology transfer office (TTO), versus just 23 TTOs when the Act was passed (Loise & Stevens, 2010).

This framework is credited by various authors as a significant contributor to the success of the United States in translating publicly funded research into commercial technological innovation, with Sampat (2006) providing a balanced if somewhat outdated review (Ciuriak & Carbonneau, 2024; Loise & Stevens, 2010; Miteu, 2024; Mowery, Nelson, Sampat, & Ziedonis, 2001; Pharmaceutical Research and Manufacturers of America, 2020; Sampat, 2006). On the other hand, it has been recognized that Bayh-Dole is sub-optimal and has been criticized as having a negative impact on basic research and creating conflicting incentives among stakeholders (Boettiger & Bennett, 2006; Kanarfogel, 2009; Kenney & Patton, 2009). Recent work has called for various reforms to the approach (Clements, 2009; Kenney & Patton, 2009). Attempts to enact similar policies elsewhere have not met with similar success, indicating that the Bayh-Dole Act is insufficient by itself and pointing to the importance of contextual differences for policy development (Ejermo & Toivanen, 2018; Gores & Link, 2021; Hemel & Ouellette, 2017; Mireles, 2007; Mowery & Sampar, 2005).

Most Canadian public research funding agencies impose no restrictions on governance beyond requiring "benefit to Canada", leaving management to the universities. As a result, Canadian institutional IP policy varies widely, without clear consensus in the literature as to the impact with respect to commercialization activity (Halilem, Amara, Olmos-Peñuela, & Mohiuddin, 2017; Kenney & Patton, 2011). Canadian tech transfer is underfunded relative to its potential value, with few funding-related incentives or external performance metrics to guide institutional investment in better practice (Freeman & Soete, 2009; Park, Goudarzi, et al., 2024; Potter, 2008). In recognition of these issues, a call for funding agencies to focus on commercialization outcomes has been made in several landmark reports (Bouchard et al., 2023; Government of Canada, 2011). The Finnish experiment on the impact of changing from inventor-owned to institution-owned IP policy is of potential interest in guiding Canadian policymaking in this area (Bengtsson, 2017; Ejermo & Toivanen, 2018).

The Effect of Firm Size on Deep Tech Commercialization

Large, established companies have a poor track record of delivering disruption via deep tech, with startup companies being increasingly recognized as more effective vehicles for commercialization of novel technologies and university spinouts being explicitly identified as key to the commercialization process (Congressional Research Service, 2012; Fraser, 2010; Haltiwanger, Jarmin, & Miranda, 2013; Keller & Block, 2013; Lanahan, 2016; Park, Goudarzi, et al., 2024; Park, Maine, et al., 2024; Swamidass, 2013; Valdivia, 2013). While large firms have been found to have an advantage in bringing new drugs to market, the literature suggest this generalizes poorly to deep tech, with Arora *et al.* (2015) noting a weaker response of private sector to government R&D support as the average size of the firm within the industry grows, suggesting potential for greater marginal impact of policy interventions that target small firms, and a shift away from internal R&D by large corporates (Arora, Belenzon, & Patacconi, 2018; Arora, Gambardella, Magazzini, & Pammolli, 2007; Arora & Cohen, 2015). Lanahan notes that "Research has found that small firms are more willing to take on risk than larger, more established firms that tend to be constrained by inertia" (Lanahan, 2016). Lanahan's work, supported by references therein and early OECD research, explicitly rejects the notion that market power and large firms stimulate innovation, noting that "R&D spending seems to rise more or less proportionally with firm size after a certain threshold level has been passed, and there is little evidence of a positive relationship between R&D intensity and concentration in general" (Lanahan, 2016; Symeonidis, 1996). Christensen provides an explanation, arguing that investment in new technologies by established companies is not a rational decision, given that disruptive markets are small and rarely profitable, putting investment at odds with maximizing short term profit (Christensen, 1997). In the author's view, this problem is exacerbated in deep tech, since the market is not merely small but may not yet exist at all.

Approaches to Managing Deep Tech by Jurisdiction

The American Approach

A preference for small firms as the recipient of public funding is a common feature of several effective deep tech ecosystems. In the United States, the Small Business Innovation Research (SBIR) program provides resources for deep tech commercialization (Ferguson & Kaundinya, 2020; Keller & Block, 2013). This program provides grants to small and medium sized enterprises (SMEs) through mandated spending by government departments on domestic procurement of novel technologies to address their challenges using a phased approach, augmented in many cases by state-level initiatives (Lanahan, 2016; Rask, 2019). While an SME is defined as having fewer than 500 employees, most awards are to startups: 94% of 2021 Phase I SBIR grants were to companies with 10 or fewer employees, 79% to companies less than 5 years old, and 69% to first-time applicants (U.S. Small Business Administration, 2021). This funding is risk-tolerant, with only 40% of Phase I projects getting to Phase II and Phase II-III success rates as low as 8% in some departments (Lanahan, 2016; Rask, 2019). In the author's view, this acceptance of a majority failure rate is a necessity in deep tech funding. Since the cost of a failure is small relative to the value of a success, it is more important to ensure that opportunities are not missed than it is to ensure return on every investment. In other words, the only way to achieve low false negative rates is to embrace high false positive rates (Cappelen, Cappelen, & Tungodden, 2023).

Canada enacted a program structurally like the SBIR through Innovation Solutions Canada (ISC) in 2017 that performed poorly both relative to the SBIR and to its own spending targets, consistently underspending by approximately two thirds (Innovation, Science and Economic Development Canada, 2022a; Southin, 2022). The budget was cut to one third of its original target in Budget 2024, bringing targets in line with actual spend (Department of Finance Canada, 2024). One study points to a failure to achieve widespread buy-in from government departments before mandating how their procurement budgets are spent, but analysis of the failure of the ISC to deliver results despite surface-level similarity to the SBIR program is a significant gap in the literature (Southin, 2022). In the author's view, differences in scale are a key issue. The SBIR funded more than 3000 Phase I and 2000 Phase II projects in 2023, meaning that most technologies arising from academic research can find a pre-existing challenge call issued under the SBIR program without requiring additional coordination between academic institutions and the government agencies issuing the calls. In contrast, at the time of writing, the ISC website listed just 19 Phase I and 8 Phase 2 projects funded in 2023, sufficient perhaps to capture the output of a single research institution. It therefore unlikely that a given Canadian academic technology that is ready for commercialization will be able to find an existing challenge under ISC, pointing to the need for a greater degree of coordination between research and early-stage, demand-driven commercialization support initiatives in smaller ecosystems.

The Israeli Approach

Favoring startups and SMEs for public funding is also evident in Israel, widely recognized as a highly effective ecosystem for technology commercialization that reflects the "whole-of-government leadership" approach to high-tech innovation called for the in the Jenkins report (Government of Canada, 2011; Lopez-Claros & Mia, 2006; Nowak, 2011). The Israeli ecosystem is highly complex and deeply interconnected by design and is discussed in several dedicated reviews (Avidor, 2011; Bar-El, Schwartz, & Bentolila, 2019; Lopez-Claros & Mia, 2006; Nowak, 2011; Stone, 2014). Where deep tech is concerned, public funding is used to follow private investment with non-dilutive government grants that incentivize greater risk tolerance in private capital, attaching strings to the government contribution that ensures long term value for taxpayers (Stone, 2014). It is the view of the author that the policy lessons from Israel—specifically, use of strings-attached public funding to follow and incentivize private sector risk taking—are more readily imported than those of the SBIR, though whole-of-government buy-in is a prerequisite: "culture and public policy are equally important in technology transfer and innovation, possibly making it difficult for other countries to copy the Israeli Innovation System" (Fischer, 2018).

There has been a recent emergence in Canada of dilutive investment funds operated by or affiliated with Canadian post-secondary institutions that work closely with university students, faculty, alumni, and tech transfer offices to provide the first source of dilutive capital to affiliated startups (the McGill Innovation Fund, the UCeed Fund, and Velocity Fund in Waterloo, for example), that often work with granting agencies to amplify the impact of their funding (Briggs, 2024b; Swamidass, 2013). The approach being taken by these funds, as well as the Ontario Centres of Innovation Life Sciences Innovation fund, are early Canadian examples of an approach to risk sharing similar to that used in

Israel. The author also notes that design of the proposed Canadian Innovation Corporation is based in part on the Israeli Innovation Authority (IIA).

The Canadian Approach

In contrast, Canada has historically not systematically favored startups as receptors of research IP. The 2020 licensing report by the Association of University Technology Managers (AUTM) shows that more than half of licensees are not SMEs, and that licensing to small companies as a fraction of total licensing deals has been trending downward for more than a decade (Novac, Vigneault, Vilkhu, & Weedmark, 2020). Combined with the emphasis that Canadian tri-council grants place on academic-industry partnerships and a need for TTO cost recovery through licensing, Canadian institutions that take ownership of research IP historically have had a structural and financial incentive to favor established companies that can provide the necessary resources over startups that are more effective vehicles of deep tech innovation, best fitting the "Traditional Shop" category in the taxonomy suggested by Baglieri *et al.* (Baglieri, Baldi, & Tucci, 2018). The author notes that the recent establishment of several institutional investment funds focused on supporting spinout activity has begun to change this in many Canadian institutions (Briggs, 2024b).

Canada's systematic favoring of large firms extends to the private sector. SR&ED data shows that 50% of SR&ED credits paid out in 2017 went to just 20 firms (Re$earch Infosource Inc., 2017). Most grants applicable to deep tech commercialization are gated by matching funding (e.g. NSERC Alliance), revenue and/or employee count minima (e.g. CanExport SMEs, Strategic Innovation Fund), or require upfront payments that are reimbursed later (e.g. NRC IRAP), sometimes without a guarantee (e.g. SR&ED) (Deacon, Laberge, Arthur, & Dlab, 2024). All these barriers favor large firms over deep tech startups.

Deep tech faces many risks, not the least of which is uncertainty about support from public programs and changes to related regulation (Bouchard et al., 2023; Briggs, 2024a; Deacon et al., 2024; Government of Canada, 2011). Startups and small firms are again disproportionately negatively impacted, especially pre-revenue, since they rarely have the resources to absorb unexpected costs or reductions in support.

A recent review of Canadian innovation funding found nearly 150 programs aimed at various stages and sectors of technology development (Deacon et al., 2024). This number represents the logical extreme of policy fragmentation. While it is the view of the author that this patchwork approach is failing to deliver results in aggregate, lack of meaningful performance metrics makes reform difficult. This failure to collect metrics of performance that correlate support today with appropriately time-delayed economic outcomes is a major barrier to evidence-based innovation policy reform (Park, Goudarzi, et al., 2024).

Canadian Culture

It is a common refrain in innovation policy debates that Canadians are risk averse, but the reality is more complex, and data that attempts to separate the impact of culture from that of policy is plagued by seemingly contradictory results. Canada's research output is strong, and Canada's Innovation Report Card finds that Canadians are entrepreneurial and willing to take risks, while other surveys find that Canadians are more risk-averse than Americans (*2024 Innovation Report Card:*

Benchmarking Canada's Innovation Performance, 2024; Plant, Veletanlic, & Ulfig, 2016). Various measures of innovation show that Canadian performance has worsened in recent years and that it is a laggard among OECD countries in terms of expenditure on R&D as a fraction of GDP, but OECD data also identifies Canada as the country with the largest proportion of innovative firms (Gama Dias et al., 2020; "Innovation Indicators Dataset," 2023; "Science, Technology and Innovation Scoreboard," 2024).

There is a simple resolution possible to the former discrepancy: while Canadians are happy to start companies, they often leave Canada to do it. Between 1997 and 2019, 41 of the 531 US-based private companies valued at over $1B USD ("unicorns") had founders educated at Canadian universities. In contrast, only 21 such companies existed in Canada, "meaning that there are nearly double the number of unicorns founded by Canadian university-educated founders in the United States as there are in Canada", pointing to a retention issue among Canadian risk-takers (Deacon et al., 2024).

A clue as to the possible cause of the latter discrepancy lies in a recent report by Council of Canadian Academies (CCA), which notes that "Canadian universities appear to create more start-ups per $100 million spent on research [than the United States]" (CCA (Council of Canadian Academies), 2023). In combination with the fact that Canada has a very large number of innovative firms, poor overall performance despite a high rate of startup creation suggests that these firms may have a survival issue, either due to early failure or early exit (Matthews & Rice, 2022). In the author's view, this reflects previously identified structural favoring of large firms in Canadian public innovation funding programs, and that better long-term tracking of Canadian university spinout outcomes is necessary.

Structural challenges to deep tech commercialization exist at the level of individual research institutions as well (Chrisman, Hynes, & Fraser, 1995). As noted in the definition, specialized knowledge is usually required to bring deep tech to market, knowledge that is typically vested with the inventors (Park, Goudarzi, et al., 2024; Park, Maine, et al., 2024). A lack of training of academics as mediators of entrepreneurship and failure to track long-term commercial outcomes with respect to success of spinout companies, the reasons for their failure, if applicable, and control over associated IP portfolios represent key areas for improvement with respect to data collection at the level of Canadian research institutions (CCA (Council of Canadian Academies), 2023; Park, Goudarzi, et al., 2024; Park, Maine, et al., 2024; Swamidass, 2013). A lack of alignment between institutional missions and tech transfer activities has also been identified as a structural issue (Bubela & Caulfield, 2010). The recently established Invention to Innovation National Network, the Lab2Market program, and the emergence of university-affiliated pre-seed investment funds in Canada, all represent positive steps toward rectifying this (Briggs, 2024b; Swamidass, 2013).

It is the author's view that Canada's innovation challenges are primarily structural, rather than cultural, but that improved long-term tracking of deep tech commercialization outcome should be prioritized as a precursor to policy development in response. University pre-seed funds are uniquely positioned to both coordinate public and private funding toward deep tech commercialization and to collect the data necessary to disentangle the contributions of policy versus culture.

Deep Tech Sectors

Quantum Technologies

Canada is a global leader in quantum technologies, boasting the highest per capita concentration of quantum companies in the world and the second most in absolute terms (Briggs, 2024a). In the author's view, the quantum sector represents Canada's best opportunity for deep tech leadership, capturing 14% of global private investment in quantum technologies in 2022, the highest per capita share of any country (Masiowski, Mohr, Soller, & Zesko, 2022). Quantum technologies are expected to have spillover impacts into a wide variety of other critical sectors, including the potential for $700B in value generation globally in pharmaceuticals, chemicals, automotive industries, and finance by 2035 (Masiowski et al., 2022). An NRC report predicted that the quantum sector will contribute $139B and more than 200,000 jobs to the Canadian economy by 2045 (Innovation, Science and Economic Development Canada, 2022b). While a 2023 report by the CCA found these numbers to be highly speculative, it still expressed optimism at the potential opportunity (CCA (Council of Canadian Academies), 2023).

In the opinion of the author, the history of quantum technology development in Canada is a roadmap for deep tech dominance based on early investment and acceptance of high technical risk. Beginning from a foundation of strong academic research, a single philanthropic investment of $170M by Mike Lazaridis in 2000 led to the founding of the Perimeter Institute for Theoretical Physics in Waterloo (Briggs, 2024a; CCA (Council of Canadian Academies), 2023). This was quickly followed in 2002 in the founding of the Institute for Quantum Computing. These investments laid the groundwork for early-stage commercialization of quantum research, and a "Quantum Valley" in the Waterloo region emerged that has served to anchor Canada's quantum ecosystem ever since. Similar early public investments, including the catalyst for the technology ecosystem centered in Sherbrooke, Quebec, provided the means for creation of key innovation ecosystems comprising a high density of both research and early-stage commercial activity (Briggs, 2024a; CCA (Council of Canadian Academies), 2023; Granstrand & Holgersson, 2020; Nordling, 2024).

The race to quantum dominance is far from over. While Canada's National Quantum Strategy is regarded as a good roadmap for advancing Canada's leading position in quantum technology research, China and others are investing heavily as well (CCA (Council of Canadian Academies), 2023; Innovation, Science and Economic Development Canada, 2022b; Innovation, Science and Economic Development Canada, 2023). Canadian public investment in quantum was $1B in 2022, 7th globally and lagging China by an order of magnitude (Masiowski et al., 2022). The plan has also been criticized for being insufficiently focused on adoption (CCA (Council of Canadian Academies), 2023). Evidence of successful deep tech commercialization from the SBIR and the IIA strongly suggest that demand-side strategies to drive adoption are key to extracting value from the foundation that Canada has already built in quantum technologies, supported by recent work on the subject (Briggs, 2024a; CCA (Council of Canadian Academies), 2023; Ciuriak & Carbonneau, 2024).

Cleantech

In comparison with quantum technologies, a subset of clean and climate technologies are well advanced in commercialization, contributing more than $20B in export revenues to Canada's economy in 2022 (Innovation, Science and Economic Development Canada, 2018; Sharma, 2024). While global clean tech investment declined in recent years, Canadian VC investment remained stable from 2022-2023 (Sharma, 2024). Despite this foundation, Canada is underperforming relative to its Copenhagen accord commitments, and Haley notes that "unless we develop new policy approaches, clean-technology sectors could fall into Canada's general pattern of innovation underperformance" (Connell, 2019; Haley, 2016; Jordaan et al., 2017).

The literature is well aligned on the challenges faced by the Canadian clean tech sector with respect to commercialization. A recent Senate report provides an excellent overview, citing a lack of cohesion across government departments and a need for the use of procurement levers to drive adoption, a recommendation previously made by ISED (Innovation, Science and Economic Development Canada, 2018; Scarpaleggia, 2023). Jordaan *et al.* concur, stating that "demand-pull policies improve the demand for lower-emission technologies specifically by creating a market through standards, increasing private incentives and encouraging learning-by-doing actions", while numerous contributions to the literature on the subject identify clean tech adoption as a multi-stakeholder issue and call for greater coordination, both between public and private sectors and between different levels of public sector (Chaloux, Paquin, & Séguin, 2015; Connell, 2019; Jordaan et al., 2017; Zhou, 2022). Market coordination and demand-driven adoption strategies go hand in hand, with Connell noting that "Implementing a governmental clean technology procurement strategy can also serve as a supplementary means of connecting the various levels of the Canadian clean tech sector" (Connell, 2019).

Several authors argue traditional venture capital is poorly suited to clean tech commercialization, leading to a reliance on foreign capital and resulting in a high rate of loss of clean tech companies (Lerner & Nanda, 2020; Malek et al., 2012; Udwin, 2015). Clean Technology Commercialization Accelerators were proposed as sources of capital positioned to help companies navigate the regulatory complexities, with an excellent review of the characteristics of these organizations presented previously (Malek et al., 2012). In the author's opinion, these observations and suggested approach generalize well to any deep tech sector that faces regulatory challenges or must engage with multiple stakeholders to deliver disruptive innovation.

Several publicly funded provincial corporations, including Alberta Innovates and Springboard Atlantic, support deep tech commercialization in their respective ecosystems and serve to coordinate multiple levels of public and private sector stakeholders, with cleantech identified as a core focus of Alberta Innovates (Zhou, 2022). Emerging university-attached pre-seed funds, while not necessarily focused exclusively on cleantech, represent another possible focal point for such coordinating activity.

Artificial Intelligence

AI is expected to impact multiple sectors and is already credited with a significant accelerating effect in cleantech (Sharma, 2024). Canada has a strong history of AI research and development, boasting 10% of the world's top AI researchers, including Geoffrey Hinton, the 2024 Nobel Prize winner in Physics for his foundational work in the field (Innovation, Science and Economic Development Canada, 2024a). Canada was the first country with a national AI strategy, is a global thought leader in AI regulation, and is highly productive per capita in terms of papers and patents (Abrassart et al., 2018; Frontier Economics, 2024; Innovation, Science and Economic Development Canada, 2017; Innovation, Science and Economic Development Canada, 2024b). In 2024, the Canadian government budget allocated $2.4B to the national AI strategy (Department of Finance Canada, 2024; Innovation, Science and Economic Development Canada, 2024b). This puts Canada on par with most European countries, but orders of magnitude behind the USA and China. The plan to acquire sovereign compute hardware has been criticized as being insufficiently focused on domestic sources for the associated procurement, failure to support domestic businesses, and a lack of focus generally (Castaldo, 2024; Goldsmith, 2024).

Evidence suggests that Canada underperforms with respect to AI value extraction where deep tech is concerned, with most academic AI IP quickly leaving the country: as of a 2023 study, only 7% of AI patents produced at the Vector Institute and Mila made it into the Canadian private sector, while 75% end up owned by foreign private sector actors and the balance remain in academic institutions (Silcoff & O'Kane, 2023). A 2021 report on the subject which noted that "Interviewees were particularly concerned over data ownership and IP" and concluded that much of the benefit of Canadian investment in AI has accrued to foreign tech firms (Brandusescu, 2021).

Where domestic adoption of AI is concerned, it has been noted that "Over one third of pre-qualified AI suppliers are international, frustrating the purpose of government (and Canadian taxpayers) investment in AI" (Brandusescu, 2021). A recent review of Canadian government initiatives with respect to AI found a heavy focus on finding applications of AI but "little focus on intervening in social and workforce development services, AI education and training, and digital infrastructure", though Budget 2024 has since allocated $50M toward workforce training (Attard-Frost, Brandusescu, & Lyons, 2024; Department of Finance Canada, 2024).

As with most deep tech sectors, it is the view of the author that a careful approach to ensuring value extraction from Canadian research IP despite a need for FDI, combined with demand-driven adoption led by public sector example, are key to securing value for Canada (Matthews & Rice, 2022). Value extraction via adoption of AI remains a global challenge as use cases are still being assessed (Enholm, Papagiannidis, Mikalef, & Krogstie, 2022). Where AI is concerned, however, there is an additional element to IP that is not present in other sectors. Training data is recognized as a bottleneck to model improvement and a safety concern for AI development across multiple fields, including other deep tech sectors like battery and medical technologies (Dubarry & Beck, 2020; Whang, Roh, Song, & Lee, 2023; Zhu, Vondrick, Fowlkes, & Ramanan, 2016). Training data has also been recognized as a key predictor of AI startup success (Bessen, Impink, Reichensperger, & Seamans, 2022). Sovereign control of training data is a key component of AI value extraction regardless of the eventual details of value arising from adoption.

Conclusions

Canada has all the raw ingredients it needs to be a globally relevant force for deep tech commercialization. While most literature agrees that Canada makes strong contributions to research, commercialization and long-term value extraction from the resulting IP remains a challenge. The literature reviewed consistently points to retention of control of IP portfolios, companies, and innovators as a key driver of this issue. Evidence suggests that addressing this challenge requires risk-tolerant public funding focused on startups and removal of systemic barriers to SMEs' ability to use it. In a small, open economy, some attrition through M&A activity is inevitable (Matthews & Rice, 2022). In the view of the author, Israel provides an example of an approach to deep tech commercialization support that balances domestic research value extraction against FDI-induced churn that can be readily adapted to the Canadian context.

There is consensus among the deep tech sectors considered that demand-side levers are a key driver of deep tech commercialization on which Canada is currently underperforming. The example of cleantech demonstrates that the role of the public sector in driving domestic demand is especially important in sectors that are heavily regulated or that have high barriers to entry that small firms are poorly equipped to navigate, and further suggests that alignment across federal, provincial, and municipal governments to guide SMEs through the procurement process is critical. However, it is clear from the failure of ISC that demand-side policies that work elsewhere must be carefully adapted to the Canadian context, considering differences in scale that make verbatim adoption of American policies a challenge, fragmentation of missions that exist within the Canadian government that make verbatim adoption of Israeli policies a challenge, and a deep-rooted risk tolerance mismatch between existing public funding programs and the realities of deep tech commercialization.

Any attempt to use public funding to support deep tech commercialization must be tolerant to a high rate of failure. The Israeli approach of following private investment with public funds provides a good example of public and private sector risk-sharing to increase the risk tolerance of both that is already starting to be adapted in a handful of examples in Canada.

Numerous deficiencies were identified in the existing literature, primarily revolving around failure to collect effective metrics of performance that correlate policy with long-term outcomes. Deep tech timelines are measured in years or decades, and program performance assessments must take this into account. The author suggests that, in line with metrics used by Park *et al.,* metrics that are time-delayed from the point of intervention such as 10-year firm survival rates and the details of how firms ended their operations, 10^{th}- or closing-year revenues, and detailed tracking of control over or access to Canadian deep tech IP assets over a 10-year timespan, are important (Arora & Nandkumar, 2011; Park, Maine, et al., 2024). Tracking of control of IP assets granted through licensing could be made an explicit condition of research funding through the tri-council agencies as part of the mandate of the proposed capstone agency.

University-affiliated pre-seed investment funds are a key recent addition to the Canadian ecosystem and are ideally positioned at the interface of publicly funded research and private investment in early-stage commercialization. These are well placed both to act as coordinators of multiple levels of public and private support for deep tech commercialization and to collect the key data required to correlate specific policy interventions with long-term outcomes. In the author's view, these entities should be prioritized as a key focal point for policy development with respect to deep tech commercialization.

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