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Original article

Mission critical: the ends, means, and design of innovation agencies

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Abstract

How should governments design public innovation agencies to accommodate the challenges of rapid technological and economic change? In this article, we argue that innovation agencies can approach innovation in very different ways. We develop a typology of innovation agencies, using eight agencies from around the world to identify distinctive patterns of learning, adjustment, and experimentation. In doing so, we demonstrate that the effective design of innovation agencies depends heavily on their mission and the specific ends they seek to pursue.

JEL classification: O31, O38, O43

Recent scholarship on innovation has repopularized industrial policy as an instrument of technological and economic change (Mazzucato, 2013; Dutz *et al.*, 2014). At the same time, this literature has demonstrated how institutional design conditions effectiveness (Breznitz, 2007b; Breznitz and Ornston, 2013; Karo and Kattel, 2016; Rodrik, 2007). Policymakers seeking to promote economic adaptation need to think carefully not only about the tools they use but also the structure of the innovation agencies that wield them. Policymakers modeling new innovation agencies on the example of successful organizations, however, could be forgiven for drawing mixed messages from the literature. Effective innovation agencies include large, powerful, pilot organizations (Wong, 2011), as well as small, lightly funded ones (Breznitz and Ornston, 2013). Some public agencies have clear technological objectives and manage much of the research themselves (Fuchs, 2009), whereas others have delegated these decisions to private sector actors (Breznitz, 2007a). Some organizations have thrived by insulating themselves from political and industrial networks (Breznitz, 2005a), while others have successfully promoted innovation by embedding themselves within these same structures (Samford, 2017). In short, there is considerable variation in the design of successful innovation agencies and no clear lessons for reform-oriented policymakers. This is a key issue, since it has now become clear that enhancing innovation is a critical mission of the state, if it is to secure the long-term prosperity of its citizens.

In this article, we cut through this confusion by arguing that there are distinct patterns of innovation, each associated with a different set of capabilities. Effective institutional design thus depends on an agency's mission or the specific type of innovation it seeks to pursue. We advance this argument in several steps. After introducing the new industrial policy

and debates over institutional design, we identify four different innovation strategies. We use this insight to develop a typology of innovation agencies, distinguishing among "directed upgraders," "productivity facilitators," "state-led disruptors," and "transformation enablers." These categories reflect different choices concerning: (i) the level of public sector R&D involvement, (ii) the positioning of the agencies within the public sector, and (iii) the degree of embedding within private industry. Section 3 illustrates how these institutional choices enabled and constrained innovation strategies by analyzing eight agencies, the Agency for Science, Technology, and Research (A*Star), the Chilean Economic Development Agency (CORFO), the Defense Advanced Research Projects Agency (DARPA), the GTS (*Godkendt Teknologisk Service* or Approved Technology Service Provider) Institutes, the Industrial Research Assistance Program (IRAP), the Industrial Technology Research Institute (ITRI), the Office of the Chief Scientist (OCS), and the Finnish Innovation Fund (Sitra). The conclusion discusses the implications for policymakers, not only as it relates to the design of effective innovation agencies but also their position within national innovation systems.

1. Designing effective innovation agencies: a mixed picture

In the late 20th century, industrial policy was widely maligned, as governments struggled to cope with rapid technological and economic change (Lal, 1983; Katz, 1998). More recent work, however, suggests that these developments challenge private sector actors as well (Weiss, 1998). Policymakers thus retain an integral role, not only in the delivery of high-quality public goods but also by connecting actors and defining markets (Rodrik, 2007; Schrank and Whitford, 2009; Breznitz and Zehavi, 2010; Mazzucato, 2013). The literature on innovation studies, for example, suggests that government agencies have contributed constructively to the performance of leading innovators from Israel (Breznitz, 2007b) to the United States (Weiss, 2014). The financial crisis of the early 21st century reinforced interest in market and network failures and the government's role in remedying these deficiencies (Teubal *et al.*, 1991; Block and Keller, 2011).

While industrial policy may be fashionable again, it differs from its mid-20th-century counterpart in several respects. Most notably for the purposes of this article, it has heeded Albert Hirschman's call to "shift from total confidence in the existence of a fundamental solution for social and economic problems to a more questioning, pragmatic attitude—from ideological certainty to more open-ended, eclectic, skeptical inquiry" (Hirschman, 1987: 30). To be clear, policymakers have retained a mission-oriented approach to innovation, pursuing "state-identified goals" to tackle "specific problems" (Mazzucato, 2017: 3). Whereas first-generation policies used the power of the state to achieve economies of scale, however, their second-generation counterparts are based on a spirit of "entrepreneurialism" (Mazzucato, 2013), "experimentation" (Dutz *et al.*, 2014), or "discovery" (Rodrik, 2007). In other words, the "new industrial policy" is based on a series of bets along an uncertain and rapidly evolving technological frontier, dropping unprofitable projects and offloading successful ones to create space for new initiatives (Breznitz and Ornston, 2013, 2018).

In designing public agencies to pursue these new industrial policies, some preconditions are clear. For example, there is widespread agreement that successful innovation agencies benefit from high levels of human capital, experienced management, and low levels of corruption or rent seeking (Breznitz, 2007b; Fuchs, 2010; Samford, 2017). Beyond these basic principles, however, there is little agreement. Some scholars, viewing the private sector as short-sighted or risk-averse, look to the state to identify new technologies, defining the scope and pace of technological development or even performing research themselves (Mazzucato, 2013; Weiss, 2014). Others, heeding the lessons of the 1970s, question the state's capacity to conduct technological research or even to define relevant problems (Justman and Teubal, 1995; Teubal, 1996). Regardless of the locus of R&D, most developmental state scholars have argued that transformative change requires agencies to assume a nodal position within the civil service (Chibber, 2002; O'Riain, 2004). More recently, however, others have pointed to the fact that highly successful agencies have thrived at the periphery of the public sector, far removed from leading developmental agencies (Breznitz and Ornston, 2013). Scholars also debate the ideal relationship of the agencies with the private sector. Some researchers emphasize the importance of working closely with industry, and established firms in particular, to gather information and facilitate the implementation of new innovation policies (Hall, 2001; Morris, 2005). By contrast, others fret that proximity to private sector networks could increase the risk of capture by established firms or industries (Johnson, 1982).[1]

1 Some have attempted to navigate these mixed messages by identifying a pragmatic middle ground in which agencies strive to achieve "embedded autonomy" (Evans, 1995) or construct private–public partnerships (Dutz *et al.*, 2014). This

2. Typologizing successful innovation agencies

We argue that these confusing and contradictory accounts can be reconciled by more fully engaging the literature on innovation. Scholars of the new industrial policy often focus on one aspect of innovation, novel product R&D. In so doing they fail to consider the complete process from the development of fundamentally new technologies to the way established products and production processes evolve within mature markets. The emphasis is almost always on novel breakthroughs, relying on game-changing technologies and new industries to generate enormous wealth and value (Weiss, 2014). Think of this as "radical innovation," where a firm or lab develops an entirely new technology. Innovation, however, can also reflect a series of small-scale improvements to mature products and production processes which continue long after the introduction of radical new technologies (Lundvall, 2002). Indeed, if the aim is to secure economic growth, then those kinds of incremental and process innovations are the unsung heroes of the capitalistic growth miracle (Rosenberg, 1983; Rosenberg and Birdzell, 1986; Mowery and Rosenberg, 1991; Baumol, 2002). Any effort to understand the effective design of innovation agencies must situate public agencies along this axis, recognizing that the same organizational model that works for radical innovation may not work for incremental innovation and vice versa.

Orthogonal to the distinction between radical and incremental innovation, we should also consider the scope of innovative activity. Innovation can be organized around a relatively narrow set of ambitious objectives or industries. Traditional literature on mission-oriented and prize-driven innovation, such as nuclear weapons or space flight, fits into this category, as well as attempts to foster innovation by targeting specific technology fields, such as biotechnology, nanotechnology, or semiconductors (Robbins *et al.*, 1972; Mathews and Cho, 2000; Wong, 2011; Kay, 2013). But innovation can also assume a more decentralized character, which delegates not only R&D but the objectives themselves to a wide variety of private sector actors. Some would suggest that the true "mission" of an innovation agency is to support such decentralized search processes, maximizing the number of objectives instead of narrowing them (Teubal, 1996).

Combining these two axes, it is clear that public innovation agencies can succeed in many different ways (see Table 1). Indeed, public interventions rarely target the innovation system in general, but instead push development in specific "directions" (Mazzucato, 2018). Innovation agencies thus guide the trajectory of innovation at varying levels of specificity (Mazzucato, 2017: 6). We distinguish among four types of successful innovation agencies, productivity facilitators, directed upgraders, state-led disruptors, and transformation enablers. Productivity facilitators introduce small-scale, incremental product and process innovations across a wide range of established industries. Directed upgraders also specialize in incremental innovation but mobilize resources around a relatively narrow range of industries and activities, facilitating large-scale change. State-led disruptors, by contrast, excel at radically innovative technological breakthroughs. Transformation enablers are also radically innovative but are characterized by a large number of small-scale experiments rather than a narrow, focused approach.

We hypothesize that these differences in innovation strategy drive the debates regarding (i) the proper level of public sector involvement in industrial R&D, (ii) the positioning of the agencies within the public sector, and (iii) the degree of embedding within private industry. As Table 2 relates, we hypothesize that productivity facilitators are more likely to benefit from deep embedding within private sector networks, which enables them to upgrade established industries by identifying relevant industrial needs and developing practical, relevant solutions to immediate

Table 1. Types of innovation agencies

		Nature of innovation	
		Incremental	**Radical**
Scope of innovation	**Focused**	Directed upgraders	State-led disruptors
	Decentralized	Productivity facilitators	Transformation enablers

intuitive synthesis obscures the diverse ways in which agencies position themselves within this space, alternately emphasizing the private or the public, embedding or autonomy (Breznitz, 2007b). Moreover, we argue that a synthetic approach, while avoiding the worst features of a purely statist, laissez-faire, embedded, or autonomous approach, deprives agencies of the benefits of specialization.

Table 2. Features of innovation agencies

Model	Organizational features	Examples
Productivity facilitator	Locus of R&D: Private Position in public sector: Peripheral Relation to established industry: Embedded	GTS institutes (Denmark) IRAP (Canada)
Directed upgrader	Locus of R&D: Public Position in public sector: Core Relation to established industry: Embedded	A*Star (Singapore) CORFO (Chile)
State-led disruptor	Locus of R&D: Public Position in public sector: Peripheral Relation to established industry: Autonomous	ITRI (Taiwan) DARPA (The United States)
Transformation enabler	Locus of R&D: Private Position in public sector: Peripheral Relation to established industry: Autonomous	Sitra (Finland) OCS (Israel)

challenges. At the same time, their close proximity to established industries limits their ability to develop radically new business models. As low-profile, peripheral agencies with modest resources, productivity facilitators are likely to rely on small-scale projects serving a wide variety of industries, but this also limits their ability to focus on innovative activities.

Directed upgraders face a different set of trade-offs. Similarly to productivity facilitators, deep embedding within existing firm networks encourages incremental upgrading and inhibits radical innovation. Unlike productivity facilitators, however, they are more likely to sit at the core of the public sector, with more resources at their disposal. This enables directed upgraders to assume a leading position relative to private industry, particularly as it relates to R&D activities. Directed upgraders can define technological development and the circumstances under which it takes place, conducting research themselves or guiding the efforts of public organizations. This enables them to focus their efforts, achieving economies of scale that are less common among productivity facilitators. At the same time, they do so within a narrow range of fields, effectively reducing the scope of experimentation.

Truly radical restructuring is more likely to emerge at the periphery of the public and private sector, in agencies with the freedom to experiment with novel technologies, new private sector partners, heterodox policy instruments, and unconventional business models. State-led disruptors combine their independence with the formidable in-house technological knowledge and R&D management capacity to pioneer radically new industries and activities. In contrast to "directed upgraders," they are less likely to be captured by established industries. However, the capacity to conduct independent R&D, at scale, greatly increases the risk of developing white elephants.

Transformation enablers are more likely to partner with nascent industries and companies at the periphery of the national innovation system, developing fundamentally novel developmental strategies and experimenting in a coevolutionary learning process over a long period of time. Because their meager resources force them to find (or help develop) new private sector partners, these agencies are less likely to fall into the white elephant trap. At the same time, their scope is limited, and they often fail to address the needs of established industries. They may also lack the resources to develop their newly found private sector partners to the point where they have a broad, positive economic impact.

3. Four models of success from the four corners of the world

To empirically elaborate on our typology, we examine eight innovation agencies, Singapore's A*Star, CORFO in Chile, DARPA in the United States, the Approved Technology Service Provider (GTS) Institutes of Denmark, Canada's IRAP, Taiwan's ITRI, the Israeli OCS, and Sitra in Finland. Each of these agencies is mission-oriented, in the sense that they are geared toward particular challenges rather than the innovation system writ large. They vary, however, in the specificity and structure of their missions. DARPA, for example, is a classic mission-oriented agency intended to identify and develop cutting-edge technologies for defense. Then there are agencies with broader scopes: Sitra, for example, was established in the 1960s with the goal of promoting private industry during a period that was

dominated by state-owned enterprises and heavily regulated industries. It did so by prioritizing technological innovation (Breznitz and Ornston, 2013). Even Canada's IRAP, while less focused and more bottom-up than Sitra, is tasked with the mission of alleviating the structural conditions that inhibit small and medium-sized enterprise (SME) growth.

Because we are distinguishing among innovation types rather than distinguishing between success and failure, we focus exclusively on successful agencies that are widely recognized for their capacity to foster innovation within their respective countries. We aim to maximize variation by comparing different patterns of success, juxtaposing productivity facilitators (GTS institutes and IRAP), directed upgraders (A*Star and CORFO), state-led disruptors (DARPA and ITRI), and transformation enablers (OCS and Sitra). Given the possibility that contextual factors such as national culture or institutions may shape patterns of innovation, we rely on a paired comparison of innovation agencies *within* each of the four ideal types. This case selection procedure is suggested for validating type specification in studies that advance typological theories (George and Bennett, 2005: 352). In keeping with most-different-systems designs (Przeworski and Teune, 1970), the agencies chosen for each of these comparisons are selected from settings with broad political–economic differences. These paired comparisons reduce the possibility that the innovation outcomes we identify are the consequence of broader political–economic conditions, rather than the nature of the agencies themselves. Despite operating within widely different contexts, we illustrate how productivity facilitators, directed upgraders, state-led disruptors, and transformation enablers share common organizational features. These same design choices that foster some types of innovation inhibit others. Analysis is based on a combination of primary sources, secondary literature, previous consulting experience, and 456 interviews conducted in four waves during several projects on national innovation agencies starting in 2000.[2]

3.1 Productivity facilitators

The GTS institutes in Denmark are an almost ideal example of a productivity facilitator. These institutions vary in size and specialization, but all work closely with private sector partners to identify and solve technological challenges. The government views them as an important policy instrument and funds roughly 10% of their activities (interviews with senior official, Ministry of Science, Technology, and Innovation, March 16, 2006 and executive, Danish Technological Institute November 24, 2005). Nonetheless, they operate at the periphery of the public service, with almost all of their budget coming from private industry. Instead of viewing the GTS as a public agency, it is better to view them as operating on commercial basis, selling services to individual firms, who define relevant needs and appropriate technologies (Gergils, 2006: 49). The institutes are thus heavily embedded within Danish industry, particularly among established firms. In total, 57% of all medium and large Danish firms collaborate with a GTS institute (Gergils, 2006: 50).

The GTS Institutes' close proximity to the private sector and the need to sell services on a commercial basis discourages them from conducting risky, long-term research, or getting involved in the creation of start-ups in new industrial sectors. In fact, while several of the larger institutes engage in significant research, the GTS institutes as a whole are a relatively minor player in the Danish R&D expenditure system. Collectively, the GTS institutes represent roughly 7% of Danish public R&D expenditure and less than 2% of total R&D spending (Gergils, 2006: 49).[3] Instead, the institutes generally draw on university research or foreign technologies to meet corporate needs.

However, the inability to conduct ambitious, long-term, large-scale R&D can also be an asset, because it encourages the institutes to apply existing technologies in pragmatic and effective ways. Learning from these exchanges, the GTS institutes have emerged as an important vehicle for technological diffusion throughout the Danish economy, either distributing knowledge to Danish firms or organizing local production networks, most notably in the "network initiative" of the early 1990s (Amin and Thomas, 1996; Ornston, 2012: 109, 110). As such, they have been credited

2 Although conducted for distinct projects, the research and interviews generally focused on similar features, namely, the relationship between private and public sector actors, the structure of innovation agencies, and the way they facilitated innovation. As a result, the cases could be constructed following George's method of structured, focused comparison. For each case, original material was reopened and reviewed using a series of "standardized, general questions" with a theoretical focus on the agency's innovation strategies and organizational characteristics (George and Bennett, 2005: 69). In this manner, we constructed similarly focused, parallel cases out of research that was originally not directed at the precise theoretical question we confront here.

3 This figure includes all R&D expenditure at GTS Institutes, publicly and privately financed.

with upgrading the Danish innovation system, enabling firms to occupy progressively more sophisticated positions within established low- and medium-technology industries (Gergils, 2006: 49–53). Their perceived success has enhanced their profile, and they are considered key actors within the Danish innovation system (Sörlin *et al.*, 2009).

While the GTS institutes thus contribute to broad-based productivity gains across the Danish economy, there is an opportunity cost to this structure. Their limited public budget and research capabilities prevent them from conducting the kinds of sustained, focused, and large-scale industrial policies that characterize other innovation agencies (see below). In fact, this has been identified as a weakness in the Danish innovation system precisely *because* policymakers rely so heavily on the GTS institutes to advance technological development (Ornston, 2012: 121–124). Moreover, their dependence on private sector partners and established firms in particular discourages the development of radically new technologies or business models. By responding to industrial needs, as expressed by individual firms, the GTS institutes have focused on short-term problems with practical solutions. As a result, policymakers have looked abroad for strategies to promote rapid and radical restructuring (Gergils, 2006: 94, 95).

While one could argue that the GTS Institutes' success as "productivity facilitators" stems from the Danish business system rather than their institutional design, one can find similar examples in different economies. In Canada, for example, IRAP is organized along similar lines and performs a comparable role in an economic setting that is notably different: a liberal, rather than coordinated, market economy, with a relatively small public sector, heavily reliant on exports of primary resources, and prosperous in spite of low levels of innovativeness and investment in research and development. In this context, IRAP is lightly resourced agency that relies on strong networks with the private sector rather than generous government funding to develop new technologies. The vast majority (roughly 85%) of Canada's federal support for business R&D is allocated indirectly through tax credits, leaving little for direct funding through agencies such as IRAP (OECD, 2016). Structurally, IRAP is one subdivision of the National Research Council and, as such, exists at the periphery of the public sector. IRAP is also an extremely flat organization (unlike most state bureaucracies). Industrial Technology Advisors (ITAs), the front-line agents within IRAP, are granted vast authority and are responsible for building networks with firms, research organizations, and educational institutions in their industry of expertise and their geographic area. ITA recruitment favors candidates with industry experience, so they bring with them the knowledge of technology development in their target industry and their network of contacts across the industrial sector in question (Breznitz and Samford, 2017).

IRAP's mission is to assist SMEs with technological innovation and diffusion to promote firm growth. Like the GTS institutes in Denmark, their embeddedness enables them to effectively address barriers to innovation. Moreover, rather than solving particular issues by developing technological solutions themselves, ITAs use their networks to locate other organizations that can assist with the necessary R&D. In doing so, they construct a framework for technological diffusion and continuous, incremental innovation. The contact between ITAs and firms is granular, with ITAs using their knowledge about a firm's products and processes to identify other organizations or firms that may have solutions to particular technological problems. A small proportion of these R&D relationships (roughly 20%) are funded by IRAP for firms that are judged to be especially promising and otherwise lack the financial resources necessary to take advantage of the partnerships proposed by the ITAs (Interview IRAP ITA, August 2, 2016). The agency's mode of operation has enabled IRAP to secure a high return on its investments in the private sector: most notably the contextual knowledge that allows ITAs to accurately distinguish client firms that need funding from those that would perform R&D without it, as well as the ability to build networks of organizations to help fulfill the needs of client (Interview senior IRAP Official, July 15, 2016; Samford and Breznitz, 2018). A 2012 external audit, for example, noted that IRAP projects resulted in additional profits (440 million CAD$) and wages, salaries, and overhead (1.1 billion CAD$) that far outweighed annual program costs (130 million CAD$), a ratio that has remained stable from year to year (Goss Gilroy Inc., 2012).

At the same time, IRAP's pragmatic and granular approach has a clear trade-off: far-reaching technology development is off the table. Because the ITAs are engaged with firms that have specific barriers to innovation and their funding is dedicated to projects with tightly defined goals, the agency does not promulgate broader or more radical innovations. While ITAs do have contact with one another, they are deeply engaged with particular client firms and the geographic regions in which they work. This pragmatic focus comes out in the language of the agents when asked about broader technology development projects: "We are very application-focused. … We don't support blue-sky research" (Interview IRAP ITA August 2, 2016). Thus, the agency's effectiveness at fostering innovation and growth stems from the aggregation of relatively piecemeal productivity improvements experienced by a large number of small firms. This incremental effect is evidenced in the particular benefits that firms identify having gained from

working with IRAP: whereas 90% of businesses improved technical knowledge or capabilities related to their businesses and 70% reported improved productivity, only 30% reported the development of novel technologies or other intellectual properties (Goss Gilroy Inc., 2012). This does not diminish IRAP's importance as an instrument for promoting innovation and growth among SMEs in traditional Canadian industries (Breznitz and Samford, 2017), but it does illustrate trade-offs that the agency embodies: it can promote incremental innovation very efficiently by embedding modestly endowed agents within the private sector, but the same features that allow the agency to excel at this mission effectively preclude its agents from promoting broader, more radical innovation.

3.2 Directed upgraders

While the GTS institutes and IRAP have functioned effectively as productivity facilitators, this is not the only way to organize an innovation agency. Directed upgraders rely on the public sector to steer technological development, rather than the private sector. Singapore's A*Star is an instructive example. Established in 2001, this centrally located, classic developmental agency was endowed with significant resources and charged with spearheading industrial R&D in Singapore (Wong, 2011: 69). As a result of its nodal position within the national innovation system, A*Star is connected to private industry, most notably the multinational corporations that dominate Singapore's economy (Schein, 1996: 100). Unlike the GTS institutes and IRAP earlier, however, A*Star is also characterized by close ties to other public sector actors. As the pilot agency for coordinating R&D, A*Star collaborates with leading institutions such as the Ministry for Education, the Ministry of Health, and the Enterprise Development Board (EDB). It also coordinates the activities of dozens of research institutes that were established by A*Star and its predecessor, the National Science and Technology Board (Wong, 2011: 69).

This structure enables A*Star to actively guide technological development. In contrast to the productivity facilitators described earlier, A*Star launched big-ticket, large-scale, long-term initiatives targeted at specific industries such as biotechnology. These focused efforts benefited from A*Star's formidable resources. For example, A*Star established a series of new research institutes without ever needing private market buy-in or financial support. In doing so, A*Star single-handedly upgraded the capacity of the biomedical industry in Singapore. By 2005, for example, A*Star-funded institutes "accounted for 38% of total biomedical R&D spending, more than the entire private sector" (Wong, 2011: 72, 73) and far out of proportion to IRAP in Canada or the GTS institutes in Denmark. A*Star's efforts were not limited to research institutes or biotechnology, extending to a wide range of other areas from technology parks to human capital (Breznitz and Ornston, 2018).

While A*Star's design enabled it to direct technological development, its embedded structure simultaneously limited its freedom of maneuver. First, the agency's high-profile position within the government discouraged it from taking risks with public funds. Instead, the agency gravitated toward conservative policy instruments, many of which were established by its predecessor (Breznitz and Ornston, 2018). Second, the agency faced intense pressure to cater to the needs of existing, politically influential industries, most notably multinational corporations. The biomedical initiative earlier, for example, was a priority of the Enterprise Development Board, which sought to upgrade foreign direct investment in this space. By colonizing A*Star's leadership and applying political pressure, the EDB reoriented A*Star toward its strategic vision (Wong, 2011: 72, 73).

This is not to deny A*Star's achievements. The agency's resources and strategic focus allowed it to upgrade Singapore's research infrastructure on a scale that dwarfed the GTS institutes in Denmark or IRAP in Canada. New research institutes, technology parks, and PhD programs enabled A*Star to reach beyond small- and medium-sized enterprises to attract investment by large multinationals such as Nestlé, Proctor & Gamble, and General Electric (Min, 2015). While upgrading foreign direct investment within a handful of targeted sectors such as biotechnology and financial services, however, A*Star did not have the radically transformative effects that policymakers initially anticipated. The agency was unsuccessful in its efforts to cultivate indigenous industry. Meanwhile, the agency's failure to develop fundamentally new industries confined its impact to specific sectors (Breznitz and Ornston, 2018).

This pattern of directed upgrading is not limited to statist or entrepot economies such as Singapore. CORFO operates in a radically different context, within a democratically elected, economically neoliberal, and largely resource-extractive economy. Despite these stark differences, CORFO has experienced similar results as a directed upgrader and is credited with playing an important role in what has been one of the most competitive Latin American economies. Like A*Star, CORFO collaborates with private sector partners, but the agency's approach is not broadly horizontal. Instead, the government has assumed leadership—with input from industry leaders—in identifying seven

"high potential" sectors that are the targets of its activity (Luna, 2017). These sectors have been defined conservatively, focusing on existing national strengths: mining, aquaculture, agriculture–food, special interest tourism, construction, creative economy, and advanced manufacturing (Rivas, 2012; Torres, 2015).[4] These sectors were determined in concert and continually coordinated with numerous other government organizations with the intent of raising the national value added to those industries.

CORFO maintains close relationships to the private sector—both individual firms and industry organizations—as a means of understanding the kinds of market failures that prevent Chilean firms from upgrading or what technologies might be imported from abroad to assist the local economy (Luna, 2017). At the same time, the agency has played a leading role in technological development, guiding innovation in the strategic areas identified earlier. For example, CORFO famously spearheaded the transformation of Chile's traditional fishing industry into salmon aquaculture (Perez-Aleman, 2005). There was clear potential for export of seafood, but the agency identified significant technological and operational leaps in the transition from traditional fishing to aquafarming. In an effort that resembles A*Star and far outstrips the GTS institutes or IRAP, CORFO worked with other agencies to fund public research, establish the Salmon Technology Institute, determine the most auspicious locations for aquafarms, and establish the collective standards that would help enable producers to penetrate sophisticated export markets. When aquaculture operations faced export losses due to fish disease, CORFO funded the collaborative effort to develop vaccines (OECD, 2007). By the early 2000, Chile had become one of the largest salmon exporting countries in the world (Perez-Aleman, 2005).

CORFO's central position within the public sector—indeed, its direct responsibility to other government stakeholders—limits the extent to which it can behave experimentally. CORFO's directory council includes not only the Minister of Economy, CORFO's parent ministry, but also the Ministers of Foreign Relations, Finance, Social Development, and Agriculture. One consequence of CORFO's accountability to other ministries and, by extension, incumbent stakeholders, is a pressure to target established industries. In 2016, only 5 of 62 new instruments were aimed at new sectors, demonstrating the weight placed on upgrading incumbent industries and close cognates (Luna, 2017). Coordination with government agencies, which have their own agendas, and constant contact with existing private sector organizations have meant that CORFO is hemmed in with regards to promoting incremental change, although it has done this very well.

3.3 State-led disruptors

State-led disruptors also take a primary role in the performance of research and technology development; however, their position at the periphery of the public sector and autonomy from established industries enable them to develop radically novel innovations. Two of our cases, ITRI and DARPA, are state-led disruptors. To this day, even after becoming internationally famous, both agencies sit at the periphery of the public sector. Further, both of them are actively involved in network creation with an ever-changing set of private firms where the agency sits at the nodal point charting out technology trajectories up to the level of specific early-stage products. The main difference between the two is that whereas ITRI is actively engaged in R&D itself, DARPA contracts out the actual R&D to external researchers, private firms, and universities.

ITRI was established in 1973 by the Taiwanese government as a multi-field public research institute under the auspices of the Ministry of Economic Affairs. While in retrospect ITRI seems to be an important central actor, in reality, it has been a peripheral agency with very modest budgets. Indeed, in parallel with ITRI, the Taiwanese government sponsored and expanded what was its main innovation agency, the Chungshan Institute of Science and Technology, Taiwan's defense technology research institute, with annual budgets that have been an order of magnitude larger than ITRI's. Further, two of ITRI's most celebrated successes in semiconductors—culminating in the spin-off of the world's largest pureplay foundaries, UMC and TSMC—had an annual budget of $5 million at its highest, a sum which is the equivalent to an accounting error in one of A*Star's projects.

ITRI's model has been used to identify and target key technologies from abroad, developing them to the level of prototype products and then diffusing them to industry, either to the existing companies or by spinning out the project teams as private companies. In addition, ITRI has been the primary breeding ground for start-ups in Taiwan with a constant stream of its researchers forming companies and stepping into careers in technological

4 Previous to this designation, CORFO had identified five strategic sectors, with construction, creative economy, and advanced manufacturing added and global business services removed in 2015.

entrepreneurship (Breznitz, 2007b). In the early days, when the high-technology industry in Taiwan was nonexistent and when Taiwan was far behind the global technological curve, ITRI's mode of operation would be to acquire obsolete technologies from foreign companies, develop them, and introduce them to the Taiwanese economy. This has been the main way in which ITRI seeded, developed, and maintained the Taiwanese semiconductor industry, from its birth in the mid-1970s until its current global prominence (Wade, 1990; Mathews and Cho, 2000; Amsden and Chu, 2003).

As the industry grew in sophistication, ITRI developed more research consortia programs, where specific industry needs and inputs were taken into consideration. Sometimes the impetus and vision for the technology came directly from industry, as in the case of cutting-edge material science research on bicycle frames, which became the technology that led Taiwanese industry, specifically Giant, to become a global leader (Noble, 1998; Mathews, 2002; Hsieh, 2015). Thus, similarly to the GTS and IRAP, ITRI cultivates inputs from the participation of industry. In contrast, however, ITRI's main mission is large-scale, multiyear R&D projects that can create, disrupt, or transform whole industries. ITRI is still spearheading decisions on new national technological trajectories; this can be seen in its more recent approach of opening international branches in some of the world's most renowned innovation centers, the first being the San Jose, California branch which opened in 2006. Nonetheless, while the success of ITRI's projects is widely recognized, ITRI is a huge organization with a history of more than four decades, and for every one of its celebrated success stories, there are multiple white elephants. Its continuous difficulties to have a perceptible impact on the Taiwanese biotech industry, even after years of attempts and billions in investment, is a case in point (Wong, 2011).

Further, while this model of state-led transformation of the economy into a rapid innovation-based one has been one of the most successful the world has seen, it has also had some less salubrious consequences. First, a division of labor has developed between private industry and government, in which ITRI conducts much of the research, and industry focuses on development. This limits the innovative capacities and the business models pursued by the Taiwanese industry. Although the sophistication of the industry has grown tremendously, interviews with some of the most advanced Taiwanese semiconductor companies still sparked comments such as: "Sometimes, I wish I was still in ITRI. It is the only place in Taiwan where real R&D is taking place" (Interview with a company CEO, January 30, 2003). Second, ITRI's strategy, by definition, is one of an extremely fast follower, never an original pioneer or pathbreaker. Hence, while ITRI constantly infuses Taiwan with new technologies and industries that are new to Taiwan, it also seems to inhibit Taiwan from becoming the place new industries, or even industrial niches, will be born.

Moving from a late industrializer and fast follower in East Asia to the United States, a large, liberal market economy that has led in radical product innovation for almost a century, we encounter perhaps the world's most famous state-led disruptor in the form of DARPA. While internationally famous, DARPA is a peripheral agency within the American public sector (see also Bonvillian in this issue). Its role is specifically to hedge, to be the small (in relative terms, in absolute terms, its budget dwarves the total national R&D investment of several nation-states) initiative that ensures that the United States will never be surprised by new technologies. For that reason, DARPA was also structured very differently than any other American federal agency. Its mission was to define cutting-edge defense-related technological projects/problems and then build up and bring together a new network of researchers from academia and industry to explore a variety of new technologies. Fuchs' (2009) discussion of the role of DARPA project managers clearly specifies their leadership role in setting the direction of the research and its overall management.

The process of determining the direction of technological development in turn reflects the needs of the military, "brainstorming" possible research directions with scientists and engineers that would meet those needs and then working with them to understand emerging technologies. Fuchs emphasizes that the first part of this process is critical and less discretionary than the latter parts. Senior military officers present in DARPA facilities act as liaisons and help managers understand the nature of the military's needs. Managers also visit military installations and observe operations throughout the country to better grasp particular military operations. Although DARPA is not itself a military agency, working closely with and taking guidance from the defense branches is a primary step that "managers cannot escape" (Fuchs, 2010: 1139). The direction of innovation is thus determined by the Department of Defense rather than entrepreneurs, firms, or researchers in the private sector.

At the same time, DARPA differs from A*Star and CORFO in that its relationship with the US military shields it from short-term political pressures, giving it the flexibility and allowing it to offer the "collaborative space" (Breznitz, 2005b; Samford, 2015) it needs to allow experimentation with radically new technologies. Historically,

the agency has developed "proactive" rather than "reactive" technologies (Block, 2008: 7), meaning that they are generally not foreseen as necessary by industry. Rather than addressing the immediate concerns of private enterprises, these research networks are able to explore openly and uncover more radical solutions in areas that are deemed important by the state.

Like ITRI, DARPA's credentials as a radical innovator should not obscure its weaknesses. While DARPA has a tremendous track record, contributing to technologies from the Internet to the iPhone, its autonomy from the private sector can lead it astray and not all projects are successful. Indeed, at any given point of time, DARPA works on several major projects, while the (rather rare) successes such as the Internet are widely celebrated, the vast majority of these projects do not have any revolutionary impact, even after an investment of several years and multi-hundred dollars on each. This is to be expected. Indeed, DARPA's mission is to hedge on the cutting edge of defense-related technologies. However, from the point of view of economic growth, one does wonder if the DARPA model does not inherently breed many more white elephants than radical, or even relative, successes.

At least as importantly, the agency relies on the formidable capacity of the American private sector to commercialize its transformative technologies. With its relatively weak ties to industry, the organization is poorly equipped to facilitate the diffusion and adoption of new technologies, particularly as it applies to traditional industry. Other countries seeking to replicate it success should recognize its limitations. As a matter of fact, it remains to be seen whether even the United States can replicate the DARPA model in other sectors, with the impact of a DAPRA-like agency in the energy sector, the advanced Research Projects Agency-Energy APRA-E, still open to interpretation. Nonetheless, this should not diminish DARPA's well-documented contributions to the American innovation system (Block, 2008; Fuchs, 2010; Weiss, 2014).

3.4 Transformation enablers

Whereas DARPA and ITRI actively shape and steer technological change, transformation enablers such as Sitra and the OCS operate more indirectly. Established in 1968 in a top-heavy, coordinated market economy characterized by incremental innovation in established, resource-extractive and metal-processing industries, Sitra was tasked with promoting free market development (Murto *et al.*, 2006: 30, 31). Officially supervised by the Bank of Finland, the agency's 145 million Euro endowment was so diminutive that it was effectively ignored by the bank and other civil servants. Veterans describe an unusually high degree of autonomy that enabled the agency to experiment with unorthodox policy instruments with little political interference (Interview with veteran policymaker, Sitra, June 14, 2012).

At the same time, the agency's modest budget and weak public sector connections prevented it from developing its own research infrastructure or funding large, long-term projects. Instead, Sitra relied on collaboration with other actors to mobilize resources. Not finding allies within the public sector, which was focused on mature, low- and medium-technology industries, and traditional policy instruments (Ornston, 2012: 37), Sitra instead targeted private companies. Since large firms and established industries had little reason to collaborate with the agency, focusing instead on more powerful organizations such as the Ministry of Trade and Industry or the Bank of Finland, Sitra was forced to strike alliances with firms at the periphery of the Finnish innovation system, in industries such as electronics that were ignored or even maligned by industrialists at the time (Breznitz and Ornston, 2013: 1226, 1227).

This freedom from public and private pressure enabled Sitra to develop a series of novel policy instruments oriented toward emerging, high-technology industries. During the 1970s, Sitra pioneered R&D grants at a time when most organizations were focused on achieving economies of scale with massive investments in physical equipment. During the 1980s, Sitra reinvented itself and Finnish industry by shifting from R&D grants to venture capital, cofounding the Finnish Venture Capital Association in collaboration with private partners. Collectively, these initiatives helped to transform Finland from one of the least research-intensive countries in the Organisation for Economic Co-operation and Development, heavily dependent on resource extraction, and Fordist-style mass production, into a high technology leader and one of the most innovative countries in the world (Breznitz and Ornston, 2013: 1227, 1228).

As successful as it was, Sitra exhibited several weaknesses. First, Sitra pioneered new policy instruments, but its modest budget forced it to rely on larger agencies such as Tekes (the Finnish Funding Agency for Innovation) and Finnish Industry Investment to scale initiatives in R&D and venture capital, respectively (Breznitz and Ornston, 2013: 1227, 1228). In practice, the agency (and its private sector partners) could only seed new initiatives, relying on

crises to elevate their heterodox strategies into mainstream policymaking and corporate circles. Second, while Sitra did not neglect traditional producers, it prioritized experimentation over distributional considerations. As a result, it was poorly positioned to navigate highly politicized issues.

Finally, the organization's success transformed the agency. Credited with creating the IT boom of the 1990s, Sitra became a target for political interference. Supervisory authority was transferred from the Bank of Finland to the parliament, which increasingly influenced Sitra's agenda. Meanwhile, Sitra has used its newfound clout to tackle high-profile public sector reforms, coordinating with municipal policymakers, trade unions, and industry representatives. In this respect, the agency more closely resembles a "directed upgrader" today. This is not necessarily a negative development, as the organization's higher profile and embedded structure could enable it to restructure public service delivery. But employees acknowledge that this requires a more incremental, negotiated approach (Interview with policymaker, June 19, 2012), while outsiders and insiders alike concede that its capacity as a radically disruptive agent has clearly declined (Breznitz and Ornston, 2013: 1230; 2018).

The OCS in Israel followed a similar trajectory, although it operated within a radically different political context. The OCS was established at a similar time as Sitra, with comparable resources (15 million Israeli lira a year), and within a similar industrial structure. Until the late 1970s, Israel was a one-party-dominated, social-democratic (heavily) coordinated market economy, relying on agriculture and traditional industries to supply both growth and employment. Into this system, the OCS, like Sitra, was injected as a small bet on diversifying the economy by increasing what was then called "science-based" industries. While benefiting from competent, professional leadership, the OCS' modest budget and low profile within the public sector led it to recruit external partners. More specifically, it targeted enterprises that were not benefiting from existing industrial policies (Breznitz, 2007a; Breznitz and Ornston, 2013: 1231, 1232).

These unorthodox collaborations with the nascent high-technology industry, combined with the agency's relative autonomy, enabled it to develop a series of radically innovative policy initiatives. Beginning with R&D subsidies in the 1990s, the OCS evolved to tackle industry–university collaboration (MAGNET), venture capital (Yozma), and business development (the Technological Incubators Program). Collectively, these initiatives transformed Israel into one of the most advanced and sophisticated high-technology producers in the world and a model for other developing countries.

Like Sitra, the OCS did not solve all of Israel's problems. In focusing on research-intensive, high-technology enterprises, the OCS ignored upgrading the traditional producers responsible for the lion's share of employment. As a result, Israel has developed a dual economy, characterized by a cluster of innovative, high-productivity, research-intensive enterprises and a low-productivity, traditional sector with few connections between them. The OCS' success in fostering high-technology growth and its failure to address these distributional concerns has led to politicization as well (Zehavi and Breznitz, 2017). While it is not subject to the same level of political interference as Sitra, the agency's status as a disruptive enabler has become an open question (Breznitz and Ornston, 2013: 1237, 1238). This realization, together with a growing understanding that its original mission of maximizing private sector R&D is no longer that relevant in an economy which now tops the world in business sector R&D as a share of GDP, led to significant organizational reforms. In early 2017, the old OCS was disbanded and restructured with the new legal status of an authority with a CEO and a board of directors, as well as a much more expansive mission. It is still unclear whether this move will allow the Israeli Innovation Authority (as it is now known) to regain its role as the disruptive enabler of the Israeli economy.

4. Conclusions

As recent literature highlights the importance of institutional design in the public promotion of mission-oriented innovation, scholars have vigorously debated the best way to structure government agencies. This article has considered whether agencies should identify specific technologies themselves or delegate this to the private sector, whether they should be situated at the center or periphery of the public sector, and whether they should cooperate with established industries or operate autonomously from them. Comparative analysis of A*Star, CORFO, DARPA, the GTS Institutes, IRAP, ITRI, OCS, and Sitra suggests that there is no single answer to these questions. Innovation agencies have flourished despite being designed in very different ways and with missions of varying scope or specificity. In short, while Mazzucato (2017, 2018) offers guidelines for the design of missions, there is no single blueprint for an effective organization. Reform-oriented policymakers can make innovation agencies central or make them

peripheral, they can embed organizations or make them autonomous, and they can strive to lead the private market or assist it. These choices enable some types of innovation but simultaneously constrain others. The research question, we argue, should not be, "What is the one most effective model?" but instead, "Which model works best to achieve specific national innovation missions?"

This conclusion differs from earlier efforts, which tried to resolve debates over institutional design by combining different elements into a synthetic model. It is certainly reasonable to conclude that innovation agencies should be structured in such a way that mixes private and public sector influences (Rodrik, 2007), combines embedding and autonomy (Evans, 1995), or operates at a mid-level between core and periphery (Breznitz and Ornston, 2013, 2018). In a sense, all of the agencies in this study incorporated these elements into their design. But this synthetic approach, while it may ameliorate the weaknesses elaborated earlier, deprives policymakers of the benefits of specialization.

Instead, we suggest that policymakers carefully consider the goals or ends that they would like to pursue; missions, after all, vary widely in scope and design (Mazzucato, 2017, 2018). Policymakers should design their agencies accordingly, recognizing the inherent trade-offs associated with particular designs. For example, agencies that aspire to upgrade existing industries benefit from embedding to learn about the specific challenges confronting industries. By contrast, radical innovation is more likely to emerge at the periphery of the economy in agencies shielded from both private sector lobbying and political interference. The development of sophisticated research capabilities and steering mechanisms may enable the public sector to guide technological development, but it narrows the scope of innovation and may weaken the prospects for commercialization. By contrast, delegation to the private sector, while less focused, may lead to broader productivity gains. Finally, we note a potential tradeoff between the ability of agencies to operate with a tightly focused mission and their ability to source technological solutions from the ground (Mazzucato, 2018).

Of course, policymakers might counter that it is too difficult to choose among the numerous, desirable objectives outlined here. A healthy economy benefits from both radical, transformative innovations and the incremental upgrading of traditional industry. Here, we would point to the importance of developing an innovation *system* in which a multitude of agencies advance different missions rather than pinning one's hopes on a single organization (Karo and Kattel, 2016). Indeed, while we have focused on individual agencies, effective innovation systems such as China, Finland, Singapore, South Korea, Taiwan, and the United States have relied on a variety of organizations rather than a single heroic agency (Koski *et al.*, 2006; Breznitz, 2007b; Breznitz and Murphree, 2011; Wong, 2011; Weiss, 2014).

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