The role of intermediate Research, Development and Innovation institutes in building regional and sectoral innovation capabilities

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Abstract

The challenges posed by the productivity puzzle in the UK need to be addressed looking at the entire research, development and innovation process, at both regional and national levels, to better understand where gaps and opportunities in capabilities lie.

In this paper, we consider international examples of Research, Development and Innovation institutes from the UK's close competitors such as US, Germany and Japan, and analyse their various missions and activities in support of national and regional capabilities. This reveals a wide variety of activities and services for the entire spectrum of actors in the ecosystem. These go well beyond the function of carrying out applied R&D at intermediate technology readiness levels.

We conclude that in the UK, Research, Development and Innovation institutes require new, more flexible, remits that include not only technology development, but broader and more comprehensive concepts of technology adoption and diffusion (including enhancing industrial absorptive capacity through contributions to workforce development).

1. Introduction and context

The role of science and technology in promoting productivity growth is influenced, not just by the overall share of resources – public and private - devoted to research and development, but by the shape of the institutional landscape in which those resources are deployed. A recent TPI working paper by one of us[1] attempted to map that landscape for the UK and supply some historical perspective on the factors that had shaped its evolution to its current state. In 2021 the UK Government had commissioned[2] the distinguished scientist Sir Paul Nurse to lead an independent review of that landscape, and this was published in March 2023[3], with a government response published in November 2023[4].

One of the goals of the Nurse Review was to *"identify whether improvements to the organisational research landscape are required to deliver the government's objective for the UK to be a science superpower at the forefront of critical and emerging fields of science and technology, and drive economic growth and societal benefit".* In a submission to the review, we argued that one set of elements of the UK's R&D landscape that is currently underdeveloped are intermediate Research, Development and Innovation (RD&I) institutes. This paper builds on that argument through an analysis of the role of such RD&I institutes in other nations.

In particular, the UK lacks institutes with a focus on enhancing the diffusion of innovation, and in providing new innovation capabilities to foster industrial value capture opportunities at the regional level[5]. The remits of these institutes should be framed in terms of industrial capability development, not just technology development. The innovation of industrial capabilities for economic value capture requires not only technology development (i.e. innovation of new technological tools, processes, etc) but also workforce development (to ensure firms have the human resources to absorb/use the new tools) and technology diffusion/adoption (to ensure the tools/resources find their way efficiently/effectively into national/regional supply chains).

Tackling issues of slow innovation diffusion and weak productivity growth should be at the forefront of the remit of this kind of RD&I institute, and should steer the activities they perform. In the current UK system, the institutions that come closest to this mission, while not completely matching it, are the Catapult Centres, launched in the early 2010s by the Coalition government. We will argue that there is scope to revisit and expand the remits of Catapult centres to fill gaps that go beyond technology development. The expanded objectives should include wider 'technology adoption/diffusion' (similar to that which Manufacturing Advisory Services used to provide) and workforce development (further supporting the absorptive capacity of firms and supply chains).

The approach we use in this paper draws on the evolution and innovation literatures[6] [7] [8]. We aim to consider the functions of RD&I institutes – that is, the set of purposes for which organisations are created (e.g. technology development, technology diffusion). These functions in turn shape the set of activities that the institutes perform, which in turn influence the evolution of functions at the systems level.

Innovation systems are complex landscapes of different types of research institutes with a diverse set of remits and goals. These may include research universities and institutes devoted to fundamental science; such institutes may be hosted by universities or be free-standing. There may be public sector research establishments (PSRE's), in support of government strategic goals such as defence, environmental protection, and health. In most advanced economies, the majority of research, development and innovation takes place in the private sector, in firms' own laboratories, and in for-profit contract research organisations. It is this private sector innovation that most directly drives productivity growth.

In the past, the mission of some private sector laboratories has encompassed quite fundamental, upstream R&D topics (the most famous example being Bell Laboratories in the USA[9]). Anti-trust action dismantled the monopoly whose rent sustained Bell Laboratories in its heyday; more generally, as Western economies have become more market-oriented, with an increased emphasis in corporate governance on generating shareholder value in the short-term, private sector R&D laboratories have tended to become more focused on immediate business goals[10]. Thus, the challenge of capturing the benefits of R&D is now greater than in the second half of the twentieth century, when private sector laboratories like Bell Labs were the source of so many key 20th century innovations. This is in line with economists' expectations that the private sector will systematically invest less in research and development than would be optimal for the whole economy, due to the inability of firms to capture all the benefits of that R&D. This is the 'market failure' argument that provides 'justification' for public spending on R&D. Yet public spending in support of private innovation can in principle take many forms[11], such as fiscal subsidies, R&D tax incentives, direct government funding R&D contracts to private sector organisations, etc. In many successful innovation economies, public support often takes the form of intermediate research and innovation institutions that involve some degree of public-private partnership in support of applied research and translation play a vital role. Examples include the Fraunhofer Institutes in Germany, the Industrial Research and Technology Institute in Taiwan, and VTT in Finland.

As acknowledged by the Nurse Review, the UK is distinguished by a strong research university base, with, in addition, some stand-alone research institutes such as the Laboratory of Molecular Biology at Cambridge and the Crick Institute in London. University research benefits from a closer connection to the talent pipeline, more scope for interdisciplinary research, and (in the UK's current funding system) a substantial cross-subsidy from the fees of international students attracted to institutions by their research reputations. Stand-alone research institutes, in contrast, benefit from a more focused remit. The UK also has some public sector research establishments (PSREs), such as the National Physical Laboratory, the Meteorological Office, and the Defence Science and Technology Laboratory, but this sector has diminished in size over the past few decades, as a result of privatisations and absorption of some institutions into universities.

The area where more weakness is perceived in recent years is the one of intermediate research and innovation institutions that carry out more applied research, usually in collaboration with industry. This was also highlighted in the 2010 Hauser Report[12], commissioned by the outgoing Labour government, and accepted by the Coalition Government. As a result, a new national network of intermediate research institutions, the Catapult Network, was founded. In many ways, the model for the Catapult Network was the Fraunhofer-Gesellschaft in Germany. A decade on, the Catapult Network has established itself as an important part of the UK's research, development and innovation landscape, even though it has not grown to the scale envisaged by Hermann Hauser. Nor is its scale yet comparable to the Fraunhofer network; in 2019, Catapult Centres received £236m in core government funding, and a further £508m in public and private grants and contracts[13], while in the same year, Fraunhofer Institutes received €746m in core funding and a further €1549 in research grants and contracts[14].

Discussion of the purpose of intermediate research and innovation institutions in the UK has focused on their role carrying out applied research in collaboration with industry. As we will discuss in more detail later, this role is conceptualised in terms of "Technology Readiness Levels" (TRL), a scale expressing a linear progression from basic research (TRL 1) to full production for the market (TRL 9), with Catapults filling a perceived gap between TRLs 4 and 6. The purpose of this note is to draw attention to the wider range of functions and activities that analogous institutions carry out in other nations, and – also building on what suggested by the Review – to point at important lessons for the evolution of the Catapult Network and the development of other intermediate research institutions across the regions and nations of the UK. In the UK, this is particularly important as intermediate research and innovation institutions are well placed to support economic development in regions with lower productivity.

Against this backdrop, section 2 briefly introduces R&I institutes and the contextual reasons for their existence in almost all advanced economies, and the major emerging economies. Section 3 provides further background in terms of what is missing in the UK landscape. Section 4 introduces a wider conception for RD&I institutes, presenting a practical framework that could be useful for policy making considerations. Section 5 presents international examples of RD&I institutes; it is important to mention that each one of the institutes discussed is strongly embedded in a specific socio-economic and institutional fabric and, thus, every recommendation and suggestion coming from them needs to be adapted to the UK context. Section 6 concludes and set some directions for future work.

2. What are Research, Development and Innovation institutes and why do they exist?

This paper focuses on the role public institutions have in the scaling up and diffusion of innovation and new technologies. Such institutions are often defined with different labels. For example, the term RTO (Research and Technology Organisation) refers to public research institutions[15] established to fulfil the research needs of public administrative bodies[16]. RTOs are nested in regions where they act as intermediaries between early stages research and more applied and commercial innovation by catalysing innovation and bringing together actors while facilitating their interaction for national purposes[17]. RIOs (Research and Innovation Organisations) are often considered similar to RTOs[18][19]. Such organisations' activities can extend throughout innovation processes that last for several decades and their activities could often include testing laboratories, development of new technology platforms, as product/process developers for local firms with a focus on user and problem-oriented research. As such, these organisations develop unique knowledge on how the major technology elements evolve over time and interact with each other[20], and on the social and technical infrastructure that make them critical for the production ecosystem over time. In the rest of the paper we will mainly refer to intermediate RD&I (Research and Innovation) institutes that are public (i.e., their remits as well as part of their funding comes from the government).

The fundamental justification for state support for R&D in general is generally framed in terms of the market failure argument of mainstream economics. This is powerful, and widely understood; however it does not go far enough. The development of technological capability and the conversion of this to economic value depends on more than R&D alone; it depends on interactions across a wider system of firms, markets and other institutions which support innovation. Failures in coordination between the elements of this system provide another powerful motivation for state intervention.

The market failure argument suggests that private investment will fall short of the optimal amount because private investors cannot capture the full return on R&D spending[21]. In fact, firms conduct R&D for two main reasons, to develop new products, services, or processes, and to maintain a capability to identify technologies. Although firms are mostly active in applied R&D – whose returns tend to be more secure – increasingly even highly applied research is becoming challenging due to uncertainty, which is another reason for underinvestment compared to the societal optimum. Uncertainty can be associated with purely market-based aspects, e.g., market conditions changing at fast pace, or to technology-based uncertainty. As the public sector applies a lower social discount rate, it will be willing to bear more risk to the returns to R&D.

R&D is an important precondition for the development of new technology-based productive capabilities, but there are a broader set of innovation activities that are necessary to unlock these. A broader technology-centred view, more closely related to corporate R&D investment decision making, takes in the dynamic process by which new technology is created and used, and considers how underinvestment can occur over the technology life cycle, which is characterised less by a continuous flow of resources, and more by lumpy investments followed by the onset of diminishing returns.

System or coordination failure is often a more appropriate perspective than market failure alone, in analysing how the imperfect operations of the wider system of innovation can lead to technologically and socially undesirable outcomes, giving a further justification for state intervention, e.g. through the establishment of RD&I institutes. This is an appropriate lens for considering the innovation process as a system where multiple actors interact[22], while performing different innovation functions in a dynamic nonlinear process where high level of coordination is required.

The literature discusses three distinct types of system failure: (i) capability failure (i.e., inadequacies in resources and performance of real firms, capability and learning failures); (ii) network failures (due to locking in into technological regimes, market or products by their history or capability); (iii) institutional failure (due to coordination and government failure or infrastructural failure, i.e., insufficient human and capital investment).[23] A system perspective is also critical to understand how to act upon some market failures that impact some actors more than others; for example, there are severe asymmetries of information in the ecosystem where firms operate, and between them. Big multinational companies tend to have more information and to exert power on smaller firms that may find themselves locked into specific activities. A further interesting element of the system approach is that it allows to consider the complexity of challenges/failures that may rise across different types of innovation activities, processes, and roles, and that they require coordination to fill gaps in the ecosystem.

To conclude, a system perspective that looks at technology life cycle requires a broader concept of technological innovation, which goes from basic R&D to industrial production and adaptation. This is especially needed in a context where technological innovation has accelerated substantially, presenting increasing challenges to value capture processes due to growing technology sophistication and complexity and increasing international competition. Against this backdrop, RD&I institutes are particularly important as they could partially substitute for the great corporate R&D Laboratories where there was both scientific discovery and early technology development with efficient and crucial feedback loops between the two[24].

3. The UK R&D landscape - and what is missing from it

There are four major components of the research and development landscape[25] in the UK. First, public sector research establishments (PSREs), such as the National Physical Laboratory, the Meteorological Office and the Defence Science and Technology Laboratory. These RIOs are sponsored by the government and in the past few decades their size has diminished as a result of privatisations and absorption of some institutions into universities. Second, there is a set of Public Research Organisations. Third, a set of independent Research and Technology organisations, private and non-profit that provide R&D services both to government and business (AIRTO). Fourth, and most interesting for this paper, there are the nine catapult centres that try to link business, advanced research and engineers. The variety of these institutions have been created over time on the basis of practical needs that emerge at different moments in time. Although they are different in their scope, subject area and missions, there are three main activities that RIOs in UK perform: i) support industrial innovation; ii) infrastructure creation and maintenance; iii) public policy development and implementation.

3.1 In the UK, internationally leading discovery science coexists with bottom of the league productivity growth and very high regional inequality

By some measures, such as world share of the most highly cited academic papers[26], the UK research system is highly successful; yet this success in discovery science does not translate into high economic performance of the nation as a whole.

The UK is currently suffering from a period of stagnation in productivity growth unprecedented in living memory; between 2010 and 2019 labour productivity grew by only 0.2% a year, with only Greece among the OECD countries performing worse[27]. Multi-factor productivity growth – representing the role of innovation in its broadest sense – over this period was essentially zero.

In addition to productivity at a national level, the UK also suffers from marked regional disparities in productivity[28]. While labour productivity in London and the Southeast is comparable with other successful Northern European economies, productivity elsewhere in the UK – particularly in the Midlands and North of England, Wales and Northern Ireland – is at levels more comparable with Southern Italy, Spain and Portugal.

The pressing question is why the nation's unquestionable science excellence has not driven productivity growth across the whole country. Three potential factors have recently come into prominence:

- The focus of government policy for some decades has been on the creation of new knowledge, rather than the diffusion of existing techniques at the technology frontier and the creation of the capacity of national and regional economies to absorb new technologies[29]. A consequence of the UK's emphasis on 'research excellence' has been that the main route to economic impact has been conceptualised as a push model of fundamental research to applications, rather than thinking through more generally how innovation can be translated into value capture.

- The UK's R&D landscape is highly geographically imbalanced, particularly in the public sector, with a preponderance of public spending concentrated in the parts of the country that are already most productive[30]. Large parts of the nation are thus left with weak innovation systems and economies with lower absorptive capacity for new productivity-enhancing technologies. In particular, public spending does not adequately support existing industrial clusters through the kind of R&D that underpins engineering development, system integration, and manufacturability. This kind of research is inevitably more specific to particular industry clusters; facilities such as pilot lines and system testbeds need sector-specific manufacturing know-how to design and manage them, and are most usefully located in proximity to value chain partners, where co-innovation with suppliers and vendors and the exchange of tacit knowledge is required.

- Third, and related to the first two points, as pointed out by Kieron Flanagan[31], the UK innovation and commercialisation model is characterised by a '*closed system fallacy*', where different activities of the innovation process (i.e., discovery and exploitation) are expected to happen in the same (already highly innovative) place. However, and especially in the last decade, discoveries in science, and technological innovations, take place widely across the world; they are indeed international activities. Today there is no inevitability that science-based research progress developed regionally or nationally will be translated into industrial R&D or value chain capabilities within the same regional or national system. Thus, it is then even more important to address the entire process of innovation and to secure that certain value adding activities happen within the country and are distributed as evenly as possible across regions. Moreover, at a time of increasing geopolitical tension, the national security dimensions of retaining national capability in sensitive frontier technologies are becoming increasingly prominent.

These points suggest that there needs to be some reshaping of underlying assumptions in the UK's science and innovation funding system; UKRI and its research councils have been culturally dominated by a particular definition of 'excellence' that has resulted in research funding in particular regions (e.g., the Southeast of the UK or the Golden Triangle). Indeed, a better distributed model that considers how innovation and commercialisation/industrialisation happen in a globalised world would benefit the UK system as a whole[32].

3.2. The Hauser Review, Technology and Innovation Centres and the Catapult Network

The weakness in the UK's translational research landscape was most clearly identified in the 2010 Hauser review[33], commissioned by the previous Labour government but warmly welcomed by the incoming Coalition government. Hauser considered the UK landscape of what he called Technology and Innovation Centres by comparison with international examples. His view of Technology and Innovation Centres was that they should be elite organisations focusing on a few areas of national priority, that combined publicly funded R&D and innovation programmes with contract research, enabling companies to share the cost of R&D. Typical activities would be the development and scaling up of manufacturing processes, and the production of technology and application demonstrators.

Technology and Innovation Centres were, at their core, conceived as bridging a gap in a linear technology development process, conceptualised in terms of “technology readiness levels”.

Hauser’s diagnosis was that the UK landscape of Technology and Innovation Centres was patchy and incoherent, supported by funding that was short-term and subscale, with a particular tendency for governments to provide some capital funding but then not back that up with ongoing revenue funding. His recommendation was the creation of a network of *“elite national TICs, which recognises their core role in the UK’s innovation system.”* This was put into practise through the creation of the “Catapult Centres”. By 2014, seven Catapult Centres had been set up (in some cases building on existing institutions), covering Cell Therapy, Digital, Future Cities, High Value Manufacturing, Offshore Renewable Energy, Satellite Applications, and Transport Systems. An early review by Hauser[34] reasserted his earlier conclusions on the need for a translational research infrastructure, and concluded that early progress had been positive and very rapid. He recommended that the network should be expanded at the rate of 1-2 a year, with a goal of having 30 Catapult Centres operating by 2030. In 2024 there are nine centres: three new centres have opened, for Energy Systems, Compound Semiconductors and Medicines Discovery, while Future Cities and Transport Systems have merged to form the Connected Places Catapult.

Hauser’s review reasserted the original criteria by which topics for Catapult Centres should be selected. These were that the topic should command a large potential global market to exploit, a UK global lead in research capability, and the necessary absorptive capacity to commercially exploit the technology in the UK. The agency charged with delivering the Catapult programme, the Technology Strategy Board (later to be rebranded as InnovateUK), added two further criteria – their potential to attract and anchor the knowledge-intensive activities of globally mobile companies, and alignment with national priorities.

What’s striking about this set of criteria is that it presupposes *existing* capabilities – in academic research, and in business capacity to exploit. Taken literally, it would mean that Catapult Centres should not have a role addressing the UK’s problems in slow innovation diffusion, or in creating new innovation capabilities in economically lagging regions where the business base does not have the necessary absorptive capacity to benefit fully from new technologies.

In fact, it is clear that in some Catapults, there has been some mission drift beyond translational research into capability development. The 2014 review already identified that some Catapults had become involved in developing human capital through vocational training, in manufacturing advisory services, and in various networking and sector development activities.

The most recent review of the Catapult Network[35] noted that neither catalysing local economic growth nor developing skills were among the core goals of Catapults. Yet the review noted that some Catapult Centres have made significant contributions in both areas, and this was welcomed by many stakeholders. The review recommends that Catapults should *“look for opportunities to support local economies, work with local partners and build innovation clusters as part of their overall strategy to support their sector or technology”,* and that they should introduce skills development into their plans – but only if this *“does not compromise core objectives”.*

In summary, there is a consensus that the Catapult Network have helped fill a gap in the UK’s research and development landscape (even though their activities are not yet at a scale that was initially envisaged). However, there is a lack of clarity as to whether their original core mission – applied R&D in emerging new technology areas – can be expanded to encompass the kind of capability development that would be necessary for them to play an important role in technology diffusion, skills development, and the building of absorptive capacity in the weaker innovation systems that characterise those parts of the UK that economically underperform. The Review published in March 2023 also acknowledges the key role that Catapults have in driving productivity growth and it states that they could also have a very important one in supporting industry, including through training and skill formation/support.

The UK’s persistent problems of stagnant productivity and regional economic disparities, however, re-emphasise the need to improve the UK’s technology diffusion architecture and skills system, as recently identified by the Council for Science and Technology[36]. To this, there is a need to clarify the role of intermediate RD&I institutes in developing innovation capability. An expanded Catapult Network could fulfil this role, but this would need an explicit redefinition of their core roles and the criteria for establishing new centres, together with new funding streams to support these activities.

4. Widening conceptions of the role of intermediate R&D institutes – from applied R&D to capability creation

As we have seen, in the UK up to now, the activities of intermediate institutes are largely focused on the generation of applied research knowledge (mid-TRLs) generally in collaboration with industry partners or other stakeholders. Their missions are typically defined in terms of particular scientific fields (molecular biology), technology domains (e.g., compound semiconductors), sectors (e.g., aerospace), or societal challenges (e.g. 'connected places').

Elsewhere (see section 5 for international examples), in contrast, the missions of intermediate RD&I institutes are often framed in terms of developing national or regional *capabilities*. There is an understanding that new *technological knowledge* is not sufficient for industrial competitiveness and economic value capture. New technologies need to have a *workforce* that can develop them into applications and deploy them in real industrial contexts. Furthermore, regional competitiveness will require capabilities to capture value at the level of the *supply chains* with the required engineering competences, facilities and resources.

Figure 1 illustrates schematically how the creation of economic value arises from the matching of industrial capability, through the development of technology, workforce and supply chains, to the windows of opportunity presented by societal needs and technological progress, A broader array of activities in intermediate RD&I institutes would also allow to better align the development of industrial capabilities with windows of opportunities, according to the industrial and social characteristics of different places.

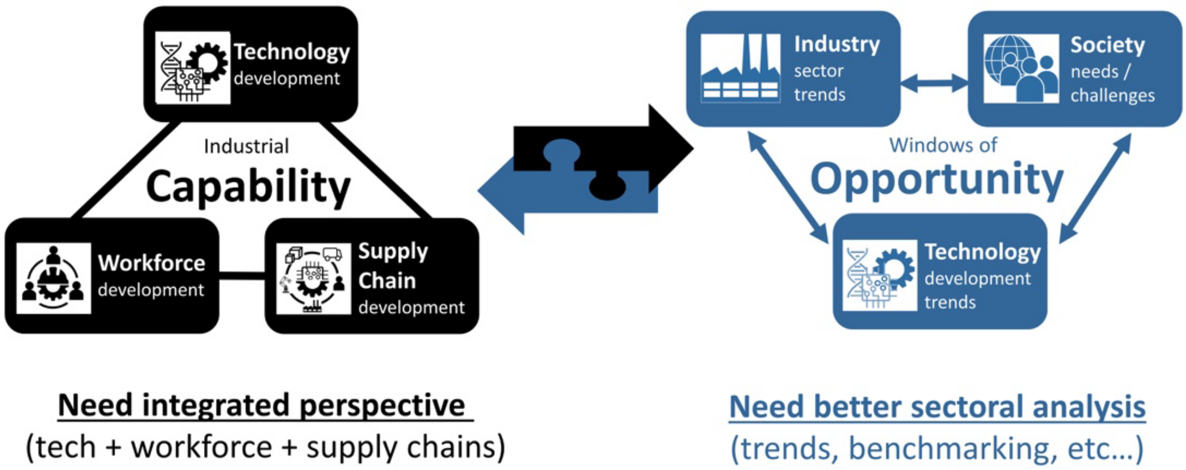

Figure 1. Matching industrial capabilities to windows of opportunity. Source: O'Sullivan

In the Hauser report the purpose of "Technology and Innovation Centres" was described as to *"bridge the gap between research findings and outputs, and their development into commercial propositions".* Here "intermediate" is interpreted literally as mediating between the stages of basic research and product and process development – "bridging the gap". This idea is formalised through the concept of "Technology Readiness Levels", originally developed in the context of the US aerospace industry. Here innovation is imagined as proceeding up a hierarchy, characterised numerically by a scale from 1 to 9, from the point of first discovery - *"basic principles observed*", at TRL 1, through to *"prototype demonstration in an operational environment"*, at TRL7.

The business of taking an innovation from TRL1 to the point of *"demonstration in a laboratory environment*" - TRL 4 – is taken to be the role of university-based research. At the other end of the scale, the development of an innovation from prototype demonstration – TRL 7 - to full commercialisation and implementation is taken to be the role of industry. The experience is that for the most part industry is reluctant to take on risky, early-stage ideas, and will generally only take up an innovation when it reaches TRL 6. Hence there is a gap that intermediate R&D institutions must fill. In addition, a further layer of complexity is given by the fact that a technology to be deployed – and even more the recent digital production technologies that are highly integrated in network systems - will need to be developed and manufactured closely (i.e., if not ‘under the same roof’, with the availability of collaboration between scientists and engineers to address the engineering development and manufacturability innovation challenges. Therefore, technological functionality may be demonstrable in an operational environment (TRL7) but demonstrating the ‘manufacturability’ of the application (sub)system in a ‘production representative environment’ (MRL7) is what might underpin local industrial jobs and economic value capture. Thus, for policy objectives such as the levelling-up agenda, R&I institutes may need also to engage with the development of capabilities/facilities to operate the kind of engineering system demonstration testbeds and/or production pilot lines which can target the manufacturability challenges/opportunities of regionally clustered value chains.

There are certainly types of products and system innovation for which this model has value, and it undoubtedly is helpful as an organising principle in some sectors, such as aerospace. Similarly in other sectors – such as the development of new drugs – there is a corresponding clearly defined pathway from laboratory discovery and development, preclinical research, clinical trials for safety and efficacy, through to regulatory approval and marketing. But there are many forms of innovation for which this simple linear picture is not applicable. Thus, too rigid a focus on the role of intermediate RD&I institutions in “bridging the gap” in a putative linear innovation pathway risks underplaying broader ways in which firms innovate and missing some of the other ways in which RD&I institutions can support productivity growth in firms, particularly through innovation diffusion and capability development. A more complete categorisation of the different combinations of innovation functions[37] [38] [39] would include the following:

- **Knowledge development:** basic science, applied science, technology development, technology demonstration, application demonstration and product/solution scale-up
- **Knowledge deployment**/capability development**:** Skills & education (graduate students, vocational training, management programme, up-skilling...); access to facilities & experts (characterisation/test facilities, contract manufacturing... new product development labs); advisory & incubation services (lean, supply chain management... incubation services for FDI corporate R&D labs)
- **Knowledge diffusion:** Network building (community seminars/workshops, consortium development, FDI-focused ‘industrial dialogue’); system intelligence (e.g. technology roadmapping services, international benchmarking...); standards & regulations (standards working groups, certification…)

In many cases, key actors in national innovation systems have a single innovation system function. In contrast, as illustrated in figure 2, intermediate RD&I institutes may need to fulfil multiple innovation system functions.

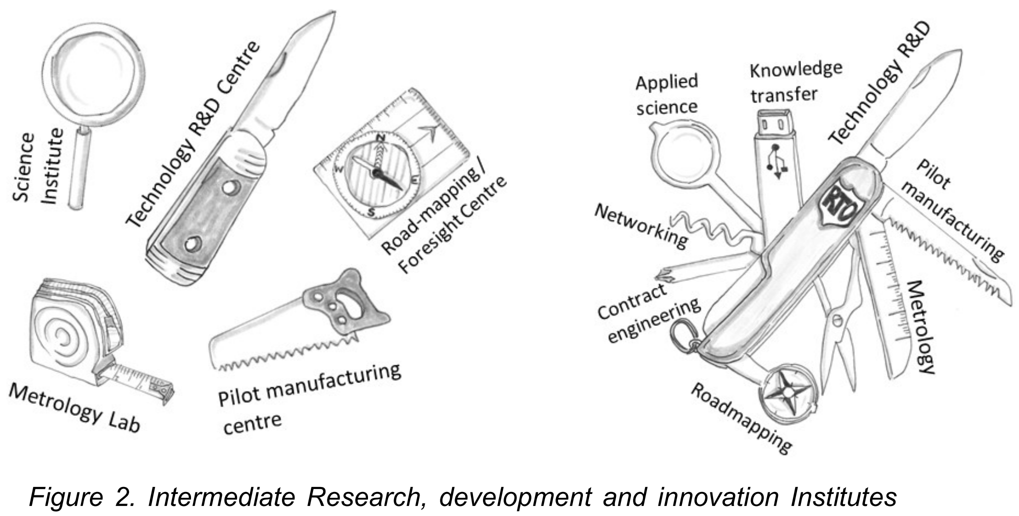

Figure 2. Intermediate Research, development and innovation Institutes can have many innovation functions beyond just technology R&D. These ‘tools’ can be used in combination – rather than in isolation - to fix

innovation bottlenecks within regions / clusters. [Cartoon © Eoin O'Sullivan]

Intermediate research institutes will only be able to make a significant impact on regional economic growth if they embrace a wider range of activities than applied research. Locally created R&D-based value can only lead to industrial economic value captured locally if technical knowledge resources are translated into industrial capabilities that are competitive with other national and international clusters pursuing the same opportunities.

There is role for carrying out applied research in intermediate technology readiness levels to meet the needs of major national firms, and with an impact on the national economy, reflecting the existing focus of the Catapults. But a greater focus on technology diffusion[40] will be more relevant to regionally clustered value chains. Even more important at the regional level, capabilities will need to be underpinned by technical and operational competences, facilities and infrastructure, distributed to relevant actors within the geographically clustered supply chains and regional innovation system. In this context, it is relevant to map out capabilities gaps, and the related activities that can be undertaken to fill such gaps, to effectively frame the division of labour across different innovation functions between different institutes – e.g., some organisations may be devoted to more technology development types of activities and others to more technology diffusion/adaptations, possibly with a focus on SMEs.

Intermediate research institutes that can build regional industrial capability by filling gaps in innovation competences and resources (the result of market failures and shortcomings in innovation systems) are likely to become both important hubs in wider research networks and anchor institutions in regional innovation systems, supporting productivity growth in the existing business base and attracting inward investment.

5. International examples

This wider conception of intermediate research, development and innovation institutions in terms of the development of national and regional capabilities is common in overseas innovation economies. Here we describe how the various elements described in the previous sections have been combined in examples from around the world. These illustrate different approaches to the design of RD&I institutes to serve socio-economic development in different sectors, with functions that address both *technology development*, and *technology transfer* and *production*. Very often, institutes that do technology transfer are also in charge of helping firms to face challenges related to the production process.

5.1. Geographical perspective: the need for a regional mission.

Research and Technology Organisation (RTO) activities in regions can be organised and funded in a variety of ways, reflecting the distinctive institutional and production characteristics different places. Examples of explicitly regional RTOs are Tecnalia (Basque Country, Spain) and the Kosetsushi Centres (Japanese prefectures and major metropolitan areas); Examples of RTO networks where institutes have regional missions (generally supported by funding from state-level governments) are the Fraunhofer Institutes and the Manufacturing USA Institutes; national RTOs with missions to support the development of regional clusters are RISE (Sweden), whose mission includes *"strengthening regional business communities and industrial clusters".* Finally, national RTO institutes with regional field offices/centres are VTT, a Finnish RTO headquartered in Espoo (near Helsinki) with branch offices in other cities (e.g., Jyvaskyla, Oulu, Tampere). In the European Union, the strategic case for such institutes in recent years has been informed by the concept of "Smart Specialisation"[41],[42],[43] , with an increasing recognition that different policies are required for different kinds of regions, reflecting their different histories and endowments.

In every case, the context provided by the wider national and regional innovation system matters, so not all approaches taken, and activities carried out in these international examples, will be effectively adoptable or adaptable to UK regions. Nevertheless, it is instructive to explore international RTO approaches to enhancing regional innovation capabilities (or addressing regional gaps in key competences or resources). If nothing else, it is worth reflecting on the implications of the role of RTOs in enhancing the competitiveness of particular international regional clusters (relative to comparator UK technology/sector clusters).

5.2. Going beyond the technology development mission

All institutes have a technology development mission as they were designed mostly to tackle commercialization and scaling up issues. However, they are different in terms of their focus on knowledge development, knowledge deployment, knowledge diffusion. For example, some of the activities supporting technology development/diffusion may (or may not) include:

Extension advisory services supporting awareness and adoption of new technology/ manufacturing/ operational innovations by addressing the gaps in knowledge, management skills, and confidence that inhibit adoption;

- Technical (tool-based) services involving testing, measurement, characterisation equipment/facilities;
- Technical demonstration services involving technology/process demonstration for potential adopters and user testbeds.

5.3. The workforce development mission

It is often argued that the most effective mechanism for knowledge transfer and innovation diffusion is through the training and subsequent mobility of skilled people. Intermediate research institutes and RTOs can play an important role in workforce development in addition to their technology development role, addressing workforce development needs that are beyond the facilities and remits of most universities or FE colleges. This workforce development role can be an important part of a mission to create regional industrial capabilities. Training activities with regional partners may offer insights into local requirements for specific competences, reveal challenges and gaps in local absorptive capacity, and help with the alignment of technology development and workforce development. RTOs that directly address workforce developments are, for example, the Manufacturing USA Institutes, the Fraunhofer Institutes in Germany, NIBRT in Ireland, SimTech in Singapore.

5.4. The supply chain mission

In addition to applied research and workforce development, the competitiveness of regional industrial capabilities may need direct interventions to promote the diffusion and adoption of existing innovations within regional supply chains, value chains and SME clusters (Conlé et al., 2021; NRC, 2013; Shapira et al., 2015). Although there is a difference between the applied research needed for the development of new technology, and the kinds of activities that support the demonstration and application of existing technologies, there isn't always a clear division between those institutes/centres that are involved in technology development, in application demonstration, and in the diffusion of innovation. RTOs that specifically look at supply chain developments are the Manufacturing Extensions Partnerships (MEPs) in the US, Kosetsushi in Japan, SimTech in Singapore, RISE in Sweden and the Mittlestands 4.0 Competence Centres.

In addition to different types of activities that may form the core of RTOs/ RD&I institutes, it is important not to define terms like 'diffusion' and 'absorptive capacity' issues too narrowly - too often they are reduced to relatively straightforward awareness/adoption challenges for smaller firms. While intermediate RD&I institutes *can* play a role in supporting awareness/adoption of relatively 'plug and play' technology solutions (along with the important work of 'manufacturing advisory service'-like programmes / FE colleges), their real contribution is when there is still significant innovation/adaptation required before the technology knowledge can be deployed into real-world industrial systems.

One difference between RTOs/ RD&I institutes in different countries is the degree to which they are optimised for the attraction of high value foreign direct investment. This has been a very significant feature of RTOs in Singapore and Ireland, for example.

We sum up different examples of RD&I institutes around the world in the table 1. It is important to consider that RD&I institutes are the result of specific institutional, historical, and cultural aspects that intend to deliver the most effective outcome for the region where they operate. Each example is also part of a broader ecosystems of institutional and actors, whose coverage/understanding is beyond of the scope of this paper. The international examples are a way to indicate that missions and functions can be design in a very diverse way, yet in all other countries there seems to be a stronger understanding and practical implementation of institutes that can serve the broad spectrum of business (and public) actors, as exemplified by Singapore and Japan.

Institute name and country	***Regional mission/focus***	***Technology development***	***Supply chain reference***	***Workforce development***	***Funding from federal/central government***
Tecnalia (Spain)[1]	X	X	X		
Kosetsushi Centres (Japan)[2]	X	X	X	X	x
Fraunhofer Institutes (Germany)[3]	X	X	x	X	X
Manufacturing USA (United States)[4]		X	X	X	X
RISE (Sweden)[5]	X	X	X	X	
VTT (Finalnd)[6]		X	x		X
SimTech (Singapore)[7]	*n/a*	X	X	X	*n/a*
NIBRT (Ireland)[8]		X		X	X
Manufacturing Extension Partnership (United States)[9]	X	X	X	X	X
Mittelstand 4.0 Competence Centres (Germany)[10]	X		X	X	
Catapults (UK)[11]		X		x[12]	X

Table 1. List of international RTOs. *With X we intend that the core mission of the different organisations included one of the elements at the top of the table. With x we point to the fact that despite not being a core function of the organisation, the activities is undertaken in one/more of the centres through different sources of funding. More detail on the international RTOs is supplied in Table A1 in the appendix.*

6. Conclusions and recommendations

This paper argues that the missing elements in the UK research and development landscape are regional RD&I institutes with a specific mandate to enhance and fill gaps in regional innovation

[1] https://www.tecnalia.com/en/home
[2] https://cepr.org/voxeu/columns/roles-japans-local-public-technology-centres-sme-innovation
[3] https://www.fraunhofer.de/en.html
[4] https://www.manufacturingusa.com/institutes
[5] https://www.ri.se/en
[6] https://www.vttresearch.com/en
[7] https://www.a-star.edu.sg/simtech
[8] https://www.nibrt.ie/
[9] https://www.nist.gov/mep
[10] https://www.ibp.fraunhofer.de/en/about-us/networks-cooperations/competence-center-planning-construction.html
[11] https://catapult.org.uk/
[12] Workforce development is not a core function of Catapults; however, there are other funding mechanisms through which some of the Catapults include training and workforce development in their activities.

capabilities. The lack of such institutes places the UK at a disadvantage in supporting the high value industry clusters across the country that are crucial for productivity growth and reducing regional inequality.

Such regional RD&I Institutes support existing and developing clusters by targeting those innovation barriers and bottlenecks that prevent firms within those clusters from taking advantage of existing and new technologies to capture high-value opportunities. These institutes need to be configured to respond to the existing business base, aligning distinctive local research strengths with distinctive industrial value capture opportunities. They must work with the grain of existing regional economies, avoiding the tendency seen too frequently in the past where nations and regions have established generic research institutes in fashionable areas such as nanotech, biotech and ICT, which fail to take root in their localities.

In other words, it is critical to keep together two arguments: on the one hand, innovation policy should steer economic transformation in socially desirable directions (i.e., in disadvantaged regions), for example as set out in the UK government's Levelling Up White Paper[44]; on the other hand, innovation policy should also target and select priorities according to the stronger potential for economic growth. Such economic growth and regional diversification, especially in less developed regions, which have been left behind by processes of uncontrolled globalisation and deindustrialisation, would need to consider unrelated diversification and transplantation of external sources of knowledge. [45] [46]

Against this backdrop, RTOs could play an orchestrating and organisational role in the ecosystem. For example, they could be the main actor in re-directing natural assets and/or existing infrastructures developed for other purposes towards a new path creation. Other scholars in the field have stressed how existing assets create an opportunity and a contextual space in which system level agents can mobilise and engage in a discovery of entrepreneurial opportunities[47] [48].

Beside the attention on regions, there is also increasing consensus on the need to focus on capabilities that are needed to perform and innovate around specific value adding activities, with institutes that are characterised by missions that are flexible enough to adjust their division of labour, research agenda and activities around technology development, workforce, and supply chain. For example, the recent Chips and Science Act aims at filling institutional gaps so to support manufacturers along the full technology lifecycle. It has become clearer that technologies by themselves do not unlock capabilities, and workforce and value chain developments are crucial to capture value at the local/regional level.

What kind of institutions most effectively support regional economies? The appropriate geography should be defined in terms of 'regionally-clustered value chains', and the focus needs to be on enhancing the industrial and innovation capabilities of that cluster, connecting regional innovation systems with regional industrial value chains. The missions of these regional RD&I institutes need to be defined more broadly than simply in terms of applied research at mid-technology-readiness-levels. An explicit regional mission should be supplemented with programmes for workforce development and innovation diffusion. International examples offer a variety of possible institutional architectures for these institutes.

For the UK, it could be that institutions that are part of, or allied to, the Catapult Network can fill this role. However, to do this there would need to be some explicit modifications of their remit and of the criteria for creating new ones. In such modifications, it is relevant to frame the conversation about Catapults (and other similar institutions) in terms of innovation capability development, rather than research knowledge development (i.e., commercialisation, translation of excellence science). Economic value capture – nationally or regionally – requires more than knowledge transfer of 'excellent' research from the university base, and it needs capability development aligned with local industrial opportunities, using Catapults/RTOs as key policy instruments for capability development. Along these lines, there would also be a strong argument, in our view, for connecting the governance of such regional centres more closely with local and regional economic governance.

Appendix 1. Table of international RTOs

RTO name and country	Mission	Services (e.g., technology, supply chain, workforce development)	Selected facts & Figures	Examples of complementary institutes in the country
Manufacturing USA UNITED STATES*	*Mission: 'to secure a future of US manufacturing through innovation, education, collaboration' by developing regional ecosystems, where there are already strengths in a specific sector. Institutes that aimed at the formation of consortia.*	*Technology development is the main goal of Manufacturing USA. Large scale collaboration with multiple organisations working together with R&D innovation projects. Three main types of activities:* ***Knowledge creation and technology development*** ***Workforce development*** ***Supply Chains support*** *Key initiatives:* • *Advanced Manufacturing Technology Leadership* • *Covid-19 Manufacturing Recovery* • *Future Manufacturing Supply Chains* • *Manufacturing Workforce Development* *Clean Energy Manufacturing*	• *The structure functions as private–public partnerships funded through cooperative agreements between the sponsoring federal agency (i.e., Department of Defense, Department of Energy, NIST) and a nonfederal entity in charge of operations. The federal funding is matched or exceeded by nonfederal sources, with a minimum 1:1 cost share* *FY 2022: $51 million ($14 million from supplement | FY 2022: $16.5 million)* • *More than 2000 project partners and ~70.000 workers trained*	• *National Institute for Standards & Technology* • *Manufacturing Extension Partnership Centers: Provides SMEs with manufacturing support services including advice on process improvement, workforce development; specialized business practices, incl. supply chain integration, technology transfer* • *National Laboratories (Dept of Energy)* • *Industry Assessment Centers (Dept of Energy, based at universities / community colleges): Conducts energy assessments for SMEs to identify opportunities to improve productivity/competitiveness, energy/ resource efficiency. Also training services.*

Catapult network, UK	*Missions differ from Catapult to Catapult. Primary functions is to de-risk the transition from research to commercial delivery.*	*Technology development and scale up.*
		*Provide **cutting-edge R&D infrastructures** including hubs, laboratories, testbeds; **technical experts** that prove and adopt breakthrough products, processes, services and technologies.*
			• *A third of their funding comes from a core grant issued by Innovate UK.*
			• *In 2019-2020:*
			  ○ *£236 million core grant*
			  ○ *£154 million commercial projects*
			  ○ *£130 mill collaborative R&D*
			  ○ *£224 mill CR&D leveraged*
			• *4,712 employees in 2020*
				• *Made Smarter*
				• *National Physical Laboratory (NPL)*
				• *Public Sector Research Establishments*

Fraunhofer GERMANY	***Mission:** promoting and conducting applied research in an international context to benefit private and public enterprise, with regard for social welfare and environmental compatibility.* *The institutes are focused on reinforcing the competitive strength of the economy in their region.*	***Research and development:** developing, implementing, and optimizing processes, products and equipment until they are ready for use and for the market.* ***Technology transfer:** industrial projects and public private partnerships, use of IP, continuing education and training for industry, spin-offs and shareholdings, transfer via individuals, standardization.* ***Training** to specialist and managers (Fraunhofer academy). There is also a platform that enables its staff to develop the necessary professional and personal skills that will enable them to assume positions of responsibility within their institute, in industry and in other scientific domains.*	***Funding (public-private):*** ▪ *Revenue from contract research** in 2021 **2.5 billion**:* ▪ ***€1.01 billion** in publicly funded project (554 mill federal government (+14%) €258 mill Ministry of Education and Research, €236mill state government (+20%), €93 mill by EU, €132 mill from universities/foundations).* ▪ ***€780 million** base funding provided by the German Federal Ministry of Education and Research and the state governments in a ratio of 90:10. Additional €93 million for retaining expertise and to help manufacturing after the crisis.*	• ***Research Institutes:** As well as the Fraunhofer-Gesellschaft, Germany has a rich landscape of complementary research institute types, including: Helmholtz Institutes; Leibniz Institutes; Max-Planck Institutes; Institutes of the Academies of sciences and humanities; as well as some state-level (Lander) research institutions* *[See www.research-in-germany.org/en/research-landscape/research-institutions.html]* • ***Aif-affiliated research institutes:** The German Federation of Industrial Research Associations (AiF) manages key government applied R&D programmes focused on SME competitiveness. AiF involves 101 industrial*

			▪ ***€723 million*** *Industrial revenues Revenue from industry contracts rose to €609 million and license-fee revenue grew to €114 million.* ***Staffing*** ▪ ***30,028 employees****, 21,640 of whom were research, technical or administrative staff, 7,877 students, and 511 trainees (end of 2021).*	*associations (with ~50,000 SME members) and ~1,200 associated research institutes.* • ***Mittlesland 4.0 Competence Centres:*** *Consortia typically involving RTOs (e.g. Fraunhofer), also universities, chambers of commerce. Offer extension services including: value chain networking, expert visits/industry 4.0 readiness assessment, strategy/roadmap development, training workshops, security advice, etc), but also have demonstration and training facilities (typically hosted by RTOs).*
AIST (The National Institute of Advanced Industrial Science and Technology), JAPAN	***Mission:*** *AIST focuses on the creation and practical realization of technologies useful to Japanese industry and society, and on "bridging" the gap between innovative technological seeds and commercialization.*	***Research & Development:*** *R&D on basic, generic technologies and technological infrastructure; long term high risk / high reward research in public good areas (e.g. energy and environment); R&D promoting innovation in domains relevant to international competitiveness and emerging sectors* ***Regional innovation:*** *AIST has 11 regional research bases with emphases on research domains relevant to local industrial strengths / regional clusters* ***Training:*** *Training units within AIST include the Innovation school - providing innovation skills for postdoctoral researchers and graduate students; Design school - developing capabilities for co-creation, marketing, business; and technical training activities, including skills development for researchers, engineers, students from firms, universities and other institutes* ***Technology consulting:*** *AIST provides consulting services to firms including: Expert advisory support, analysis and evaluation, commercialization support* *New Marketing & Business Development Headquarters (since 2022): Carries out formulation of business concepts; execution of empirical projects; promotion of AIST-initiated start-ups. Its organizational structures include: Cooperative research laboratories with partner companies; open innovation labs; participation in Technology Research Associations*	***Staffing*** • *Approximately* ***2900 employees*** *of whom ~2200 are researchers (July 2022)* • *A further approximately* ***4250 visiting researchers*** *from industry (~1500), universities (~2000), and other public sector research establishments (~750) [FY 2021]* ***Funding:*** • *Revenue of ~ JP¥111 billion (including JP¥63 billion core funding; ~JP¥7 billion facilities; JP¥26 billion in commission research) [FY 2021]*	• ***Kosetsushi:*** *regional public technology development and transfer organisations within regional innovation systems. Provides access to technical facilities such as testing equipment and analysis tools and by providing technical/engineering consulting and advisory services, and seminars for engineering education.* • ***SME Support Japan*** *(SMRJ): Provides business advisory services to SMEs through SME regional support centres, including business consultation, business matching, expert visits, training* • ***Riken:*** *Riken is a major scientific research institute in Japan mainly funded by the Japanese government. It has ~3,000 researchers carrying out basic and applied research across a range of scientific domains. Annual budget ~ ¥88 billion*

Table A1. Selected case studies of international RTOs.

Appendix 2. Current and future research projects at CSTI

This policy paper is informed by current work led by the CSTI (Centre for Science Technology and Innovation Policy). Specifically, an in-depth analysis of RTOs and their division of labour is carried out under the research theme of national and regional manufacturing strategies. As effective policy design requires a deep understanding of technologies' life cycles, their innovation process, and the capabilities' gaps around which policies are designed, it becomes more relevant to understand how the process happens and how it can be improved. Locally created R&D-based value can only lead to economic value capturing locally if technical knowledge resources are translated into competitive industrial capabilities. RTOs provide services that are of crucial importance for technology development and technology transfer. Such activities require technical and operational competencies, facilities and infrastructure distributed to relevant actors within the geographically clustered supply chains. As discussed in this policy paper with reference to the UK, governments have designed mechanisms for RTOs to tackle challenges at different levels of the innovation process. Our research is both at the theoretical and empirical levels, intending to provide useful frameworks and tools to study RTOs and to strengthen our framework in a way that could serve policy-makers to address existing and future challenges in the UK. In particular, we are conducting a comparative case study on the US and UK ecosystems, focusing on the challenge of digital technology innovation and adoption processes.

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