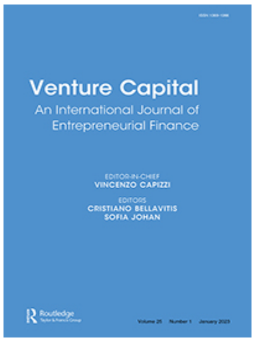

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The role of the university entrepreneurial ecosystem in entrepreneurial finance: case studies of UK innovation knowledge centres

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The role of the university entrepreneurial ecosystem in entrepreneurial finance: case studies of UK innovation knowledge centres

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ABSTRACT

How to commercialize university research and create positive socio-economic impact is a fundamental research question that is under explored. Considerable public funds are invested in universities globally to create knowledge and then to explore its viability to exploit commercial value through supporting entrepreneurship. We explore how publicly funded research and commercialization of projects promote university's science and technology (S&T) initiatives. Qualitative case studies, involving 45 interviews, examine three UK government-funded Innovation Knowledge Centres' (IKCs) roles in commercializing three different emerging disruptive technologies: cyber security, digital construction and synthetic biology. An improved entrepreneurial finance ("entfin") ecosystem is the catalyst to promote innovation, through public funds to empower industry and deliver an effective finance escalator. A "WHO" policy analysis framework examines: the "Why" rationale for public investment; "How" process of translation; and "Outcomes". This identified how Entrepreneurial Finance combined with Intermediaries, Infrastructure, Training and Leadership impacts scientific research commercialization. We reveal several inter connectors that link maturity of projects, their locality and outcome horizons. Universities play an important intermediary role, regionally and globally to connect the wider entfin ecosystems. The conclusions suggest that government needs to improve the policy mix across university ecosystem actors to improve long horizon investment.

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Entrepreneurial finance; innovation universities; policy appraisal; science and technology ecosystem; entrepreneurship support

1. Introduction

How to fund and commercialize university research and create impact? This is a fundamental question asked by researchers, policy makers and financiers. Universities are major anchor institutions (Finger et al. 2016) and knowledge bases (Brown and Mason 2014) in research-oriented ecosystems which positively promote research and development (R&D) and enable entrepreneurs to exploit under realized potentials. Successive governments, both in the UK and internationally, heavily invest in research at universities

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to promote university's science and technology (S&T) initiatives. There is belief that S&T coupled with entrepreneurial education will provide a conducive environment for new innovative spin-outs that will exploit cutting edge technologies to gain competitive advantages. The S&T initiatives help to support regional and national economies through upskilling labour and introducing efficient enterprises which contribute towards tax revenues that can enhance local and national environments and contribute towards improved living standards (Griniece, Reid, and Angelis 2015). Despite significant investments, Hsu et al. (2021) report that US universities contribute only one seventh of the value of the private sector from their patents and related licensing and start up initiatives. They argue that the difference is due to lack of sales, marketing and distribution capabilities, alongside the information asymmetries that exist between universities and buyers. Fundamentally, for universities to advance their innovations, they need to fund improved commercial development by utilizing the commercializing skills of private investors (Owen and Vedanthachari 2022). Hence, it is established that the combination of public and private finance plays an essential catalytic role for commercializing university research (Etzkowitz 2012; Graham 2014; Pique, Bergbegal-Mirabent, and Etzkowitz 2018).

2. Motivation for the research

The motivation for this research is to scrutinize the procedures adopted by universities to conduct and exploit research knowledge translation from fundamental academic research, through R&D into impactful industry innovation. To gain in-depth knowledge of entrepreneurial finance, it is important to examine the connectedness between various agencies that promote R&D within the university sectors. To understand the dynamics of entrepreneurial development and innovation within the university sector, this study focuses on entrepreneurial education and training in S&T, together with private as well as public financial institutions. A considerable literature, over several decades, has identified a significant entrepreneurial finance gap (Deakins and Hussain 1994) and more specifically within the domain of S&T research and its exploitation (Mazzucato and Semieniuk 2018). This limits exploitation of university research and innovation and, hence, leads to economic welfare loss. Yet, there is limited research that explores how the finance gap negatively impacts innovation and realization of economic potentials of universities' research (Lerner 2010; Wright and Fu 2015; Munari et al. 2016; BEIS 2017).

A key research gap therefore relates to understanding the financing requirements and role of public policy in encouraging university S&T-related entrepreneurial initiatives during the pre-seed stage of financing. This stage is associated with overcoming the initial information asymmetries (North, Baldock, and Ullah 2013) between university researchers and entrepreneurs or industry to establish commercial proof of concept, prior to private investor seed stage R&D and prototyping (Munari, Sobrero, and Toschi 2018). This requires understanding of public policy approaches by drawing from evaluation literature (Weiss 1998) to examine the Theory of Change (ToC) of public supported S&T translation models.

Qualitative case studies adopt a 'WHO' approach, addressing three key questions for developing an effective university S&T entfin ecosystem: (i) "**Why**" public policy is required; (ii) "**How**" university-industry innovation translation takes place to commercialize fundamental research; (iii) What are the types of "**Outcomes**" delivered? The paper's central focus is the specific knowledge gap around funding the translation. However, in taking a holistic entfin ecosystem view the paper also concerns how this pre-seed finance stage relates to the further stages of the innovation finance escalator and delivery of commercial, socio-economic outcomes. However, a caveat of the latter question is that public policy early-stage investment outcomes may take many years to be fully realized and understood, since they are related to the varying investment horizons for different disruptive technology's adoption into the market (Owen 2021).

This explorative paper contributes to literature at three level to the university "entfin" literature.

Firstly, we examine the wide range of actions undertaken by university research centers to develop their entfin ecosystems to commercialize their scientific research. Second, the paper contributes to information asymmetry theory by explaining how universities can act as a conduit to achieve initial early-stage private sector investment to fund the innovation and enable the finance escalator to support new and established enterprises to advance Technology Readiness Levels (TRLs) and successfully commercialize. Third, the paper offers a nuanced approach to improving understanding of three different next generation technologies (the emerging technology platforms; cyber security, digital construction, and synthetic biology) and their respective investment horizons.

Whilst the paper is limited to the UK context, it examines three distinctive case studies that consider different emerging university technology platforms which are backed by the UK Innovation Knowledge Centre (IKC) programme. These offer deep insights into the funding and support requirements for research translation into commercialization and the nuances relating to technology maturity and short horizon software versus longer horizon deep tech capital investment activities (Owen 2021; Owen and Vedanthachari 2022). The paper should therefore be of value to innovation finance theorists, practitioners, and policymakers globally. This paper is organized as follows: the university entfin ecosystem literature review, research approach, emerging thematic findings, discussion and contribution, and conclusions outlining the limitations and future directions for this research.

3. Research context – the university entfin ecosystem

Innovation ecosystems are vital for the economy. Moore's (1993) seminal paper gave birth to the idea of "innovation ecosystems" that examines the nature of competition and its context. Moore (1993) suggested that innovation takes place where there is an ecosystem with multiple industries, where ideas and knowledge enable them to develop products and services for the mutual benefit of all. The process is repetitive and knowledge expansion is all inclusive and augments over time (Moore 1993, 76). However, Valkokari (2015) differentiates innovation, knowledge, and business ecosystem by stating that knowledge ecosystems create new knowledge and technologies, whilst business ecosystems focus on creating customer value and innovation ecosystems tend to integrate knowledge and business ecosystems. Thus, universities are knowledge creators and perform a critical function to promote, support and develop innovation ecosystems, but need to effectively connect with the business ecosystem.

The Startup Genome report (2020) stated that future economic growth will come through start up ecosystems. These are an amalgamation of diverse stakeholders such as businesses, universities, funding bodies, physical working space advisory organisations, etc. Finance providers play a vital stakeholder role, with Startup Genome's evaluation of 70 ecosystems across the globe allocating 25% weighting to funding providers. Hence, entrepreneurial finance is an essential pre-curser to innovation and new start-ups (SQW/CEEDR 2019). The term entrepreneurial finance is all inclusive (Owen, Lyon, and Brennan 2018), in that it refers to all sources of finance, private and public. The last decade witnessed an emergence of new finance providers for startup firms, resulting in the disruption of traditional linear financing pathways. Bonini and Capizzi (2019) find that these include a range of dedicated sources of finance, including equity-based and debt-based crowdfunding platforms. These emerging, innovative approaches have significantly developed the operations of risk capital finance providers, especially those who tended to fund the established enterprises that aspired to reposition their business operations.

Despite these new entrants, information asymmetries still exist between new ventures and potential funders. This is exacerbated within the university context, resulting in few research ideas reaching commercialization (Startup Genome 2020).

There is diversity in terms of what is considered as the university entfin ecosystem. However, there is consensus on the Triple Helix inclusivity (Samila and Sorenson 2010) of interconnectedness between higher education and state support. This can facilitate an enabling environment through providing regulation and policy for universities to work with new enterprise and existing private industry and the allied financial services to innovate (Finger et al. 2016; Clarysse et al. 2014). Deshpande and Guthrie (2019) find limited consensus in defining the university's entrepreneurial ecosystem. However, they found wider appreciation of the term relating to universities supporting the entrepreneurial role to promote economic development, both at regional as well as national level.

Within the UK, recent work by SQW/CEEDR (2019, 2022) points to diverse models, scale and linkages of entrepreneurial ecosystems. These can be highly localized into local science park business clusters, but also extend across regions, nations and globally. A simplified generic framework developed from multiple literature reviews sets universities as a key pillar of the wider entrepreneurial ecosystem, which also includes finance and business support, infrastructure, people and skills and facilitatory leadership and networking linkages that connect to innovative startups and firm developments (See Figure 1; SQW/CEEDR 2019, 39). It is noted that this all sits within the realm of public policy, regulation and international relations (SQW/CEEDR 2019).

4. Theoretical background - information asymmetry

Information asymmetry is a key theory in management research. Bergh et al. (2019) reviewed and identified the application of the theory for a number disciplines, such as strategic management, corporate social responsibility, human resource management, organization behaviour, international business, and entrepreneurship. Information asymmetry can be studied from multiple perspectives such as the factors that contribute to information asymmetry, actions that can be taken by actors towards information asymmetry, implications of information asymmetry and how it can be exploited. Within the study of entrepreneurial finance, the concept of information asymmetry as a key factor in accessing finance has been studied extensively (Akerlof 1970; Myers and Majluf 1984). Information asymmetries are most acute within the earliest business startup stages where founders will have greater understanding about their business potential than potential

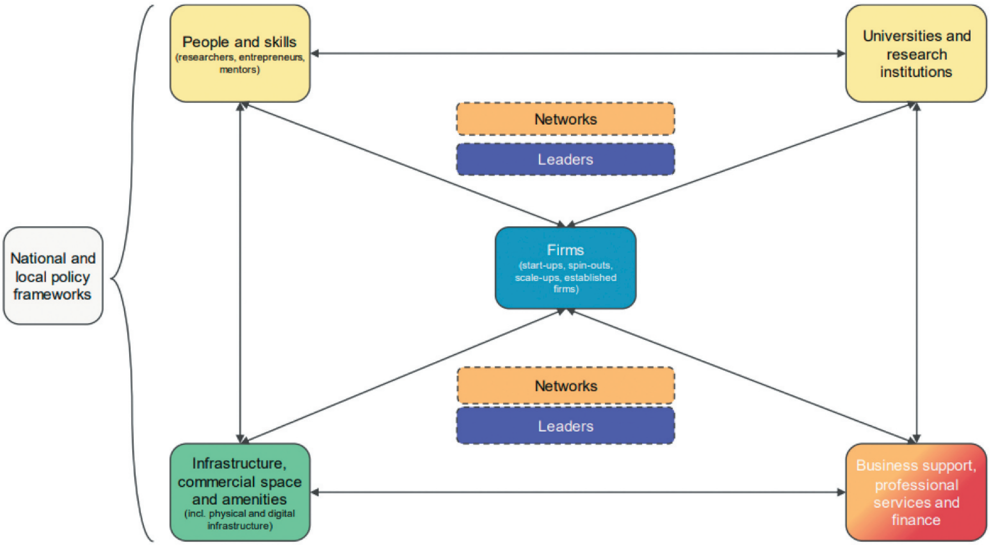

Figure 1. The university entrepreneurial and finance ('entfin') ecosystem.

stakeholders and investors. In the university context this may be particularly pronounced as it is widely believed that academic research scientists do not typically use language that can be easily understood by industry (SQW/CEEDR 2019). Moreover, they are less likely (than, for example, serial entrepreneurs) to have appropriate connections and resources for developing networks with investors (North, Baldock, and Ullah 2013). Research scientists and university executives therefore need to find the most effective solutions to overcome this information asymmetry problem. This requires consideration of what the commercial target markets for the research will be and how to develop communication linkages to these industries and appropriate financing mechanisms to support commercialisation. A major problem associated with science and technology, deep tech, blue sky research is the long lead times associated with progressing TRLs. This phenomenon can create information asymmetry problems, particularly with regard to the timing and approach to communicating with investors and industry stakeholders about TRL stages. Owen (2021) and Harrer and Owen (2022) find that this is particularly problematic for new disruptive technologies (like cleantech), which are not well understood by investors, since they lack the strategic investment hurdles that are recognisable in longer established markets (such as pharmaceuticals, where Corporate investors frequently invest at trial stages prior to commercialisation). Information asymmetry, therefore, forms the theoretical underpinning to understanding the interactions of the IKC programme with industry and financiers, which are explored in three case study emerging technology contexts.

5. Role of venture capital in the entfin ecosystem

Entfin theory is based on the information asymmetries extant between new enterprise creations and potential funders. Burger and Udell (1998) attribute this to opaqueness of information. As businesses become more mature they become less opaque and easier for potential investors to make investment decisions. Several studies (North, Baldock, and Ullah 2013; Mason 2017; Owen, Deakins, and Savic 2019) report that finance for pre-seed funding, proof of concept and market research are largely supported by UK government grants and informal business angel investment.

Venture capital (VC) institutions have gained a central position in the UK, serving as financial intermediaries to provide risk capital support to emerging enterprises (Mason 2010, 2017). Formal VC providers first emerged in the US in the 1950s, and subsequently gained traction globally, including the UK. Studies by Lerner (2010) and Owen and Mason (2019) evidence that contemporary VCs serve an important support role in terms of embedding R&D within universities and facilitating innovative spin-outs (Clarysse et al. 2014). However, an extensive recent literature examining early-stage innovative ventures reports persistent private finance gaps, presenting the need for public funding bodies to intervene to fill the gap (Lerner 2010; North, Baldock, and Ullah 2013; Lee, Sameen, and Cowling 2015). Nevertheless, few (Lehner, Harrer, and Quast 2018) explore the existence of long horizon patient capital gap for emerging S&T projects. S&T enterprises tend to disproportionately suffer from private finance gaps (Mazzucato and Penna 2016; Owen 2021), yet there is a dearth of research into the role of entfin to support the university innovation to commercial impact through spin-outs or commercial spin-off into industry collaboration stage (Pattnaik and Pandey 2014).

6. Role of public funding for fundamental research

There is emerging evidence of government initiatives to overcome the university pre-seed finance gap. These provide funds to support projects to gain proof of concept (PoC) and seed VC investment to progress potential commercialization of university research outputs (Munari et al. 2016; Munari, Sobrero, and Toschi 2018). At the same time university research has been exploited through the increasing numbers of incubators designed to convert concepts into commercial outputs (Kochenkova, Grimaldi, and Munari 2015). However, policies associated with spins off and university incubators are complex as they are influenced by the central (national) as well as regional stakeholders (Borrás and Edquist 2013). Government, central as well as local, has developed policies promoting regional/local specialisms to support ever growing numbers of entrepreneurs. It was recognized that different enterprises required varying and different approaches to enhance their effectiveness and productivity with an appropriate level of funding (Wright and Fu 2015). In particular, it was found that funding to support the linkage between the VC and industry had to be reflective of the location within which the enterprise and universities were situated and the specific industrial cluster. The university's reputation or sectoral standing had a positive correlation with their level of success, with research suggesting that higher tier universities spin-outs from incubations were more successful in attracting VC funding. This success was attributed to social as well institutional networking; thus, universities' higher reputation reduces barriers for start-ups to attract external funding (Baroncelli and Landoni 2017). However, these studies do not explain the range of activities and processes universities adopt in translating fundamental research ideas into a business backed by VC funds. They, therefore, point to the need for further university S&T entfin policy studies (Munari, Sobrero, and Toschi 2018).

7. University and S&T innovation

To embed university spin-outs (and spin-off), universities have dedicated Technology Transfer Offices to access external finance for spin-offs (Brandli et al. 2015; Munari, Sobrero, and Toschi 2018) and deal with associated contractual matters relating to commercializing ventures. A closer relationship between academics and industry is beneficial, as evidenced by the experiences of Boston and San Francisco universities. In both cases a closer relationship has yielded positive benefits (Brandli et al. 2015). It has been suggested (Munari, Sobrero, and Toschi 2018; BEIS 2017) that it is essential that a combination of university concept grants and follow-on VC seed investment is available to enable the projects be fully exploited. Studies by Munari, Sobrero, and Toschi (2018) and BEIS (2017) examined how universities can support S&T innovation to commercialise. Universities and VCs both require a critical mass of activity to bridge the gap between firms with high-tech activity and access to finance (Florida and Hathaway 2018). The emerging evidence reported by Florida and King (2016) and Nathan and Vandore (2014) supports "hard" and "soft infrastructure" development to facilitate information sharing between the university and industry knowledge via local networking neighbourhood cultures (Nathan and Vandore 2014).

Universities' S&T enables them to offer two services to enable private sector innovation. First, universities provide the environment and knowledge for the private sector to undertake research that promotes innovation within the firm. Second, universities have competitive advantage in terms of infrastructure and knowledge that enable firms to undertake R&D in collaboration with the academic institutions. Universities are ideally positioned to share fundamental research with industry that provides opportunities to innovate. These activities, when effectively funded, provide foundation for new businesses to innovate (Hauser 2010). A plethora of researchers (Mazzucato and Semieniuk 2018) have identified major obstacles that firms with long horizons and large capital-intensive investment requirements to innovate and commercialize new technologies face. There is market failure to meet such niche requirements, therefore, there is scope for the public funding bodies to support ventures (Owen, Deakins, and Savic 2019). This funding market failure is also identified by the British Business Bank UK Equity Tracker (BBB 2021), which reported a funding gap for "deep-tech" firms. These findings suggest that government co-financing schemes, which range from Patient Capital Funds for seed to scale-up ventures to predominately earlier seed-stage Enterprise Capital Funds and Angel Co-investment Fund, aim to support the deep tech firms at different stages of commercialization to enable them to succeed and grow and reduce private finance market failures. Successive research, (Owen, Lyon, and Brennan 2018; Owen, Deakins, and Savic 2019; Owen et al. 2020) indicates that to reduce fall out rate at each successive finance stage, adequate funds and support need to be provided for deep tech innovations to commercialise.

8. Enabling innovation through the university entfin ecosystem

The literature related to university ecosystem demonstrates that practice embedded within theory has contributed towards the generation of "input – process – output/outcome" models for explaining the research commercialization process, such as:

(i) **input measures**, according to Graham (2014) include research funding and emphasise S&T investment that focuses on developing facilities such as incubators, labs and science parks (Loots et al. 2020). Rissola et al. (2017) and Graham (2014) also highlight soft issues such as recruiting experienced S&T experts, including graduates, post-doctoral graduates and industry specialists. Technology Transfer Officers (TTOs) also perform an important function in connecting the research and technology ecosystem with S&T infrastructure (Stam 2018). Ranga, Peralempi, and Kansikas (2016) also suggest non-financial factors, such as individual leadership as a key agent for the progressive ecosystem.

(ii) **Process measures** are fundamental for this research and key to TTO operations. However, these features are linked with the effectiveness of leadership and governance (Stam 2018). This process is connected to the level of investment with the associated industry and their funding, government grants and private funding support; for example, into incubator and accelerator activities that enhance production capabilities (Regional Ecosystem Mapping EC 2020; Graham 2014; Bedford et al. 2018; Rissola et al. 2017).

(iii) **Outcomes** - policymakers are driven by job creation and GVA impacts and not necessarily by the numbers of direct spin-out companies and their wider innovation impacts (Graham 2014; Bedford et al. 2018; Rissola et al. 2017). Komorowski (2019) suggests consideration for the boundaries of the ecosystem in the context of specific university contribution (Rissola et al. 2017). European NUTS3 regional analysis (Regional Ecosystem Mapping 2020) also suggests that the full economic benefits of research and innovation may be positive, but there is time lag between the innovation and operationalization of the concepts and their commercialization. This is important, since emerging deep tech innovations with long horizon and large capital requirements are central to this research.

Literature relating to an entfin ecosystem suggests there is a need to explore the range and types of funding models accessible to the embryonic stage of S&T deep tech innovative ventures (North, Baldock, and Ullah 2013). To facilitate R&D and translate this with the output, the entrepreneurial framework needs to be aligned with public funding and co-financing programmes. However, consideration should be given to the specific sectors and their financing structures. For more established sectors, such as life sciences, investment within these sectors can be evaluated and risk assessed based on past experience, whereas for new tech platforms the same is not possible (Owen, Deakins, and Savic 2019). In addition, timeline to exit the investment varies from shorter horizon, under five years, for digitech, whereas other investments, such as deep tech, can take decades to reach repayment exit (Owen et al. 2020). Figure 2 illustrates the stages involved to convert research into a VC or Corporate supported enterprise. The framework illustrates how TRLs are supported by the private and public finance initiatives through the finance escalator, progressing from pre-seed through to large-scale post commercialization scale-up. This framework presents a theoretical linear "idealised" approach for translation from a macro level. However, it is recognized that the translation process will differ due to technology, sector, access to finance, etc. With this in mind a broad overview of UK university S&T and the role of the IKC programme in translating fundamental research into industry innovation is presented. This effectively answers "why"

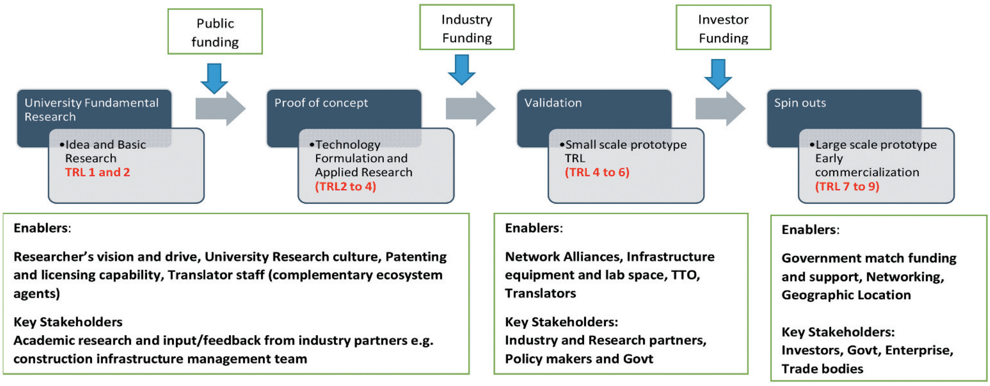

Figure 2. Conceptualization of the university entfin ecosystem escalator framework. Developed from Graham (2014), Stam (2018) and Bedford et al. (2018).

public support and funding is required in the form of the IKCs and the proposed Theory of Change (Weiss 1998) that the programme offers for addressing this.

9. Background to the UK government S&T programmes

Ulrichsen () estimated that between 2003–18 UK universities produced 3,000 IP-based spin-outs, whilst their S&T reach into the economy is far greater through industry linkages. This demonstrates that the UK is the largest national university S&T market in Europe. UK government policy interventions have increased since Hauser's (2010) and subsequent 2014 reports, the latter drawing on the IKC pilots. These suggested that the UK leads in university research activity but " … *fails to capitalise on research, hence fails to fully realize economic benefit*". Hauser (2010, 5) thus advocated for the UK to form strategies to develop " … *platform technologies to tap into multibillion pounds per annum, worldwide markets, as the UK has competitiveness in areas such as financial as well technical leadership. The platform will enable the UK universities and industry to jointly realize full benefit from collaborative research that links research to manufacturing*."

Considering competitive advantage enjoyed by industry and universities, the UK Research Partnership Investment Fund (UKRPIF) and IKCs were established to develop strategies to support technology platforms, such as TRLs 3–6, to exploit feasible proven research, thereby supporting commercialization TRLs 7–9. To achieve these objectives National specialist Catapult centres were set-up in 2013 that supported nine strategic sector groups which bridged independent centres with universities and the industry to accelerate commercialization of emerging research. The aim was to connect researchers, support agencies and financial institutions to provide holistic strategic ecosystem to support viable research.

10. UK Innovation & Knowledge Centres (IKC)

The focus of this research is on the role of the UK **Innovation Knowledge Centres** (IKCs) programme established in 2007. IKCs are central for the UK's strategy to commercialise emerging research and to adapt technologies to foster a critical industry mass in emerging disruptive technologies. The Theory of Change (Weiss 1998) is the basis to link IKCs as university research centres that have attained international quality research capabilities to acquire technologies necessary to exploit research and innovation. University-based research is led by academics but they are supported by entrepreneurial teams dedicated to promote the research and innovation. The whole ecosystem is designed to enhance the large and small businesses research capabilities and to translate research into successful industry innovations. To date £98.5 m has been invested in three rounds of funding, beginning with two pilot centres at Cranfield and Cambridge funded in 2007–2012 and a further six centres, spanning emerging materials, biotech and digitech. IKCs are designed as training and de-risking vehicles for business partners, providing academic and industry co-working facilities with an emphasis on early-stage collaboration. They enable enhanced understanding of emerging technologies and address the market drivers that underpin their economic potential. Successful examples of university-business collaborations include proof-of-concept, lab work, secondments and demonstrator studies, which are key in the route to commercialisation. IKC success is reflected in increased industrial investment and business creation around each centre and their wider roles as industry market leaders, shaping national policy and regulations and extending influence as leaders within global research networks, opening up markets for major exports of cutting-edge knowledge-based services, products and processes. Notably, IKCs are a revenue stream for staff and project funding, whilst the considerably larger £900 m UK Research Partners Investment Fund (UKRPIF), established in 2012, has co-financed strategic university S&T capital funding investment (eg for lab space), representing a potentially effective programme mix (Belmana and CEEDR 2018).

11. Methodology

The methodology examines how universities' research can be translated into economic value from a financing perspective. A qualitative multi-sourced case study approach was deemed appropriate (Eisenhardt 1989; Yin 2009; Creswell 2009; Goffin et al. 2019) for this type of exploratory research. Since IKCs were established with the primary objective of translating the emergent most promising technological platforms from fundamental research into new billion-dollar industries (UKRI 2021), they present an ideal case for studying this phenomenon. Research began with an extensive structured literature review (Tranfield, Denyer, and Smart 2003; Nightingale 2009) to examine how entrepreneurial finance assists universities to the commercialize applied university research. Using Scopus (the largest global academic paper search programme) 10 (higher level ABS 3+) publications were recognized from the last two decades directly addressing the university entfin ecosystem in the UK or related mature financing economies (e.g., North America and Europe). Additional Internet search offered contemporary practice and policy grey literature, suggesting current best practice guidance for university research commercialization and how public finance can accelerate the process. Of the six currently established IKCs, three were chosen for this study.

The case study IKCs were selected on the basis that they have operated long enough (about a decade) to observe financial inputs, translation processes and socio-economic outcomes. The selected IKCs operate within sectors that employ varied and promising global reaching technologies and are located within different regions – Queens University Belfast (QUB) cyber security in Northern Ireland, Imperial College London synthetic biology ("synbio"), and Cambridge University Centre for Smart Infrastructure and Construction (CSIC). This diversity of projects and technologies enabled the researchers to obtain detailed insights about the nuances between technology maturity, investment horizons and financing structures. Prior research indicates that one approach may not be applicable to all scenarios and technologies (SQW/CEEDR 2019). Hence multiple and diverse case studies were chosen. In addition to the case studies, additional interviews were conducted with Southampton University's Biofilm sector IKC and Cambridge University's Maxwell Centre which was supported by the UK Research Partnership Investment Fund (UKRPIF) to embed S&T within local industry. These additional interviews provided richer background on how IKCs operate and issues related to capital infrastructure investment for fundamental research commercialisation. To overcome researchers' interpretative bias, two researchers captured and evaluated qualitative case study data (Eisenhardt 1989). The data captured from interviews was entered into Excel spreadsheets to facilitate evaluation of core themes systematically (Pratt 2009); the key text was coded and agreed by a group of researchers (Miles, Huberman, and Saldana 2014). The results from the findings were also triangulated with management reports and the UKRI secondary data and then sense-checked in three follow-up IKC online workshops, in Summer 2021.

The qualitative research was designed to triangulate multiple stakeholder evidence (Yin 2009) from the university entfin ecosystem. Of the 45 interviews, 35 online IKC interviews were conducted during COVID-19 in Autumn, 2021. The IKC interviews were segmented to ensure coverage for each IKC of IUK Funding body oversight staff, IKC centre management and administration, specialist commercial translation staff, assisted businesses, including SMEs and some spin-outs and related key industry stakeholders (trade bodies), policy leaders and IKC board members (see Table 1).

Each IKC had unique project management structures and translatory roles for delivering projects, which were additional to existing TTO activities. Interviews utilized a topic guide approach, drawing on prior research experience with UKRPIF (Belmana and CEEDR 2018) and examined university entfin ecosystem literature. This suggested examining leadership, goals and objectives and "input-translation actions-output" models and longer term expected outcomes (relating to Theory of Change and underlying logic model approaches; Weiss 1998 – and our "WHO" approach). Additionally, the guides explored emerging technology roadmaps, strategic networking, lessons learned with regard to translation processes and financing commercialization and future plans. The

Table 1. Breakdown of case study interviews (2021).

IKC/Case Respondent Category	CSIC	CSIT	SynbiCITE
Management and Administration	2	3	2
Specialist IKC Tech translation staff and TTOs	3	4	2
Businesses (SMEs), including direct spin outs*	4(1)	4(2*)	3(2*)
Stakeholders and industry specialists	1	1	1
UKRI programme managers		2	

Additionally: 3 interviews were held with Biofilm IKC, including manager, stakeholder and SME case study; 10 interviews were undertaken on-site with Cambridge Maxwell Centre (UKRPIF) programme in 2017, including managers (2), researchers (4) and SMEs (4).

tailored topic guides for IKC staff, stakeholders and IUK policy leaders were piloted with Southampton's Biofilm IKC (forming useful supporting data), refined and then formed a consistent exploratory approach for the 3 IKC case studies' interviews (Goffin et al. 2019).

12. Empirical findings

Findings from the literature review and explorative interviews with IKC programme managers and UK policymakers (from UK Research and Innovation (UKRI)) suggest how universities' fundamental research can catalyze leading-edge industry innovation. This innovation has the potential to create new jobs, exports and increase local, regional and national GVA. However, barriers exist between the translation of new ideas and concepts developed within universities and industry commercialization, representing a gap in connecting university fundamental research with industry innovation and commercialization. The barriers relate to two forms of finance:

(i) **resource finance**, for premises, equipment, staffing, internal networking (e.g., between TTOs and different faculties to clarify IP and encourage commercialization activities), and external networking and outreach activities;
(ii) **project finance** to catalyze and support industry related innovation projects.

This qualitative analysis of key informant interviews from three distinctive IKC case studies revealed five core themes (Table 2): industry communication expertise, research resource access, project finance, developing skills and management, academic leadership and networking. These, in combination, demonstrate the ways in which the public funded IKC programmes were able to overcome commercialization barriers within different university entfin ecosystem contexts and through different technological platforms: cyber-security, synthetic biotech and construction infotech, located respectively at Queen's University Belfast (Centre for Secure Information Technology – "CSIT"), Imperial College London ("SynbiCITE" centre for synthetic biology) and Cambridge University (Centre for Smart Infrastructure Construction – "CSIC").

12.1. Theme 1: communication experts – industry decoders/engineers – moving beyond IP

There is need to bridge the communication gap between university researchers and industry innovators. IKCs provide finance for the universities to acquire staff with relevant skills sets from industry to translate their research outcomes and enable their adoption for industry innovation. A business partnership manager at CSIT stated "*Academics love to do blue sky research and they speak in a language that industry struggle to understand. Moreover, they are driven towards publications and research outputs rather than solving practical problems. Translation engineers fill this gap by taking academic research to businesses"*. Associated professionals, such as lab technicians and software engineers, offer technical support to industry which is different from the legal (IP) and administrative work of TTOs which is typically referred to (Munari et al. 2016).

A key role of the IKC Theory of Change is to empower staff with expertise of translation to support the evolving platform technology to deliver real life application, promote

Table 2. Evaluation of IKC's selected themes.

IKC/Theme	Belfast CSIT Est. 2009 cyber security	Imperial SynbiCITE Est. 2013 synbio	Cambridge CSIC Est. 2011 smart infrastructure
Funding	**Core IKC Funding**: **£14m** Other Public Funding: £34M Private Funding: $1M Hardware Nvidia £25k annual membership revenue	**Core IKC Funding: £12m** Other Public funding: £50m+ supported by £100m+ leveraged private funding	**Core IKC Funding: £14.9m** Private and Public Funding: £16.8M
Why: Theory of Change	Working with SME innovators and larger companies to adapt academic research software libraries and develop new software for industry applications	Focusing on spinouts and early-stage SME innovators, offering launchpad, PoC grants, lab development and financing links to develop tech route map to sustainable industry standards and solutions	Offering PoC trials for large infrastructure construction companies and offering opportunities for SME innovation uptake for smarter information standards and adoption
How: Translation Ecosystem Themes			
Communication	15 translation engineers	Design and Facilities key staff	Post Doc collaborative facilitation
Accessibility	Membership forum, corporate steering group, Labs programme (LORCA extended to London) Online delivery from 2020 NI Cyber cluster outreach programme	Bio design + facilities hub equipment access services – expanded by London White City Biofoundry (2017) Industry/research link/partners (60+), organize Synbitech - Europe's largest annual event	Industry PoC demonstrator free service promotion and provision Workshops (online), exhibitions (eg ICE superheroes), conferences Partnership with Alan Turing Institute
Financing (projects)	Project engineering (free software trials/support to some SMEs and members) PoC/grants (EU, KTP, IUK) Lorca 72 ventures raised £160m investment	PoC/pilot project funding (£400k) Business outreach hub, investor consortium, Rainbow seedfund £200k collaboration, industry club, House of Lords investor meetings £1m+ IKC investment: £1.6m+ co-finance	PoC demonstrator post doc projects Lab rental Private partner investment/ grants (KTPs, EPSRC, IUK)
Skills & Management	MSc in Cyber Security Lab accelerator training	4 Day MBA foundation programme, lean launchpad accelerator, tech seminars	25 Secondments, industry collaboration, workshops, training
Leadership	Government advisor for cyber security Participation in global research network, overseas trade missions	Authored UK roadmap for synthetic biology; Founding partner – Global bio foundry association; Synbio event	Construction standards and policy documents; smart sustainability round table/ Global Engineering Conference
Key Outputs (KPIs)	17 lab graduate companies (+72 Lorca) Titan-IC/Nvidia spin-out 40+ companies directly supported 100+ MSc cyber security grads	Assisted 80+ companies, 40+ intensive lab assists and 27+ PoCs plus 1 pilot 100+ MBA grads (7 universities) 2500+ event attendees	3 spin outs (Utterberry, Epsimom, 8Power) + Cemoptics (Skanska) 62 formal partners 200+ PoC demonstrators
Outcomes	2,200+ jobs in Belfast/NI Contribution to a cluster of 60 + new companies worth £80m GVA International inward investment form large corporate back offices Created high value jobs (48.5k av. Salary; reg av. £28k)	Development of UK-wide roadmap of 7 University network of synbio centres Directly assisted company valuations of over £1bn Contributed to c. 200 synbio SMEs/W. London cluster – 250+ jobs International collaborations with NUS Singapore, Berkely, Stanford	33%+ material/time savings in infrastructure new build and refurbishment National and international research collaborations including South Korean bridge infrastructure programme

Source: Authors findings for the IKC case analysis.

industrial innovation and build capacity. Translators appointed by Imperial (SynbiCITE) proved extremely successful. One such example is a bio lab manager who connected academics with industry through lab-sharing and guidance with big data; a second example is, where an analytics and metrology specialist directly assisted startup and scaleup progress. At QUB (CSIT) attention was first given to promoting the activities of the center to industry in order to encourage membership and interaction with companies ranging from start-ups to large corporates. To achieve this, two posts are recommended: first, an industry development manager to liaise with industry and academia to develop cyber security software, thereby enabling industry to access latest concepts; second, a lab technician from industry to provide support for new software companies and products. There was realization at CSIT that, with few exceptions, academics were not equipped to support the specialist translation of research. Thus, Invest Northern Ireland provided an additional 5-year grant to fund 15 "translation engineers" with specific industry experience to assist businesses to operationalize academic research-based projects. The construction industry lacked research to innovate, hence lacked fiber optic sensor technologies when compared with manufacturing. To fill this gap, Cambridge (CSIC) developed a collaborative approach to negotiate access to large-scale construction projects to test their advanced IT equipment with remote sensing capabilities on hard infrastructure projects such as HS2 high speed trainline and London's CrossRail. To support this collaborative industry research, IKC funding was sought to pay for post doc researcher time to showcase PoC and negotiate industry staff time input to identify the data that will yield high practical industry impact. To operationalize the project, the IKC relied upon their industry connections and notably their IKC founders contacts. In addition, CSIC recruited an industry experienced academic specialist in fiber optics to further develop industry links and tests.

12.2. Theme 2: provide access to cutting edge equipment

No IKC funding was allocated for building lab infrastructure. Rather, the programme's ToC supports the operation of innovation labs that enabled industry translation to take place within the university sited facilities. This is where university-based research translation staff can work hands-on with entrepreneurs and private industry staff. Critically, the IKC's revenue-based programme could not operate in isolation without suitable policy mix support from capital-based lab and equipment funding programmes like UKRPIF.

QUB's original IKC plan focused on providing a small amount of incubation space for cyber security software start-ups and early scale-ups and was superseded by the IKC's leading role in LORCA (£13 m) a UK Department for Digital, Culture, Media and Sports (DCMS) funded London lab accelerator programme. This has given QUB's IKC far wider national presence and access into London's global tech skills to provide an industry leading accelerator. CSIC mainly relied upon existing older technology – describing their activities as translation via "*TRL 7–9 know-how demonstration*", instead of collaborating with Cambridge labs. However, our company interview evidence found that they use Cambridge University's labs, such as the Maxwell Centre, to test physical materials science and engineering. This facility was built in 2016 at the cost of circa £70 m, of which £21 m was funded by UKRPIF. It enables enterprises to conduct research, over short-term, especially at early-stage of exploration. Silicon Microgravity (SMG) was a small business that benefited from cross-cutting interdisciplinary lab work. Their collaboration with CSIC started when the centre relocated within the civil engineering department. SMG's initial project for acceleration and gyro sensors for autonomous vehicles was, through CSIC collaboration, also developed to map buildings and underground pipes.

The case of SMG and CSIC illustrates the benefits of sharing state of the art technology to enable SMEs, which otherwise will not be able, to translate their ideas into practice. The same view is supported by SynbiCITE. The IKC was initially restricted in lab space at their South Kensington campus to offer other researchers and businesses. However, since they acquired funds (£160 m, including £50 m UKRPIF) and relocated to West London, within a multi-disciplinary setting, they have offered more access to external researchers and businesses. In addition, they have established the White City Biofoundry, including new technology investment of £3 m. This cutting-edge technology now offers opportunity for them to test business ideas, concepts and run a full test cycle of works. The lab's 6 bench facility, with technical support and help from postdocs, has encouraged small firms to access hitech facilities to undertake research.

The benefit of providing lab access was acknowledged by the CEO of LabGenius, a spin-out from SynbiCITE. The lab facility provided access to postdoc researchers who were funded through IUK grant to carry our work on gene sequencing. The company successfully gained, through Imperial Innovation, an IP and used the data generated to raise $3 m in 2017. Currently, LabGenius continues to collaborate with SynbiCITE. They have received $30 m investment and employ Imperial graduates and currently benefit from accessing SynbiCITE's £500k gene sequencing equipment. Without such cutting-edge equipment, small companies would not be able to pursue research, nor test ideas. The CEO acknowledged technical and financial support received: "*SynbiCITE provided all the assistance required to start and develop our pioneering AI protein sequencing business and raise the funding required to do so. Without this support the business would never have started*".

12.3. Theme 3: offer seed funds (PoC, free trials/demonstration projects)

Prior empirical evidence reports that financial subsidies are essential for small businesses at the translation stage, a need currently served by the IKC. Siegel, Veugelers, and Wright (2007) suggested that public policy ToC adopt proof of concept (PoC) project financing approaches that address the very early-stage information asymmetries in universities' new tech that are most challenging. Munari et al. (2016) suggest that PoC grants offered at regional and national scales are important to enable small businesses to access lab facilities. However, the IKCs offer more adaptable and industry sector-nuanced approaches than previously reported.

Grants awarded by PoC, operated by IKCs are flexible; managers of Southampton (National Biofilm Centre) and Imperial (SynbiCITE) suggested that these offered more flexible and faster approval than national IUK grant programmes. Furthermore, peer review of applications by industry experts are preferred because their feedback offers specialist input, whilst the process also includes academics. Owen (2021), reported IUK's process has been criticized for lacking practical commercial industry external peer reviews.

Imperial's evidence suggested PoC grants supported enterprises located in West London that worked with IKC industry translators. The translation staff provided extensive accelerator skills support, additionally offering non-technical know-how in terms of networks, financial training and market research: "*To enable enterprises to pursue viable cases to the next stage of investment, they require training*". Flexible funding proved to be effective, for example in one case where a flexible extended £100k grant overcame private market failure. SynbiCITE management reported that very few funded companies failed and £400K of grants has assisted 28 companies that have created a combined value of over £1bn.

At QUB three cohorts of the CSIT lab accelerator programme led to 17 companies graduating, prior to the enlarged, separately DCMS funded LORCA programme, based in East London's Olympic Park. The labs programme features engineer support to translate cybertech research into workable industry innovations. Specialist QUB staff provide technical software and AI computing support, alongside more standard business finance, marketing and networking assistance. These services have been planned, promoted and staffed through IKC funding alongside other significant funding contributions from UK and Northern Irish public bodies and specific project grant and knowledge transfer applications supported by IKC staff. QUB also offers free software trials to member organisations, with smaller SMEs being offered low/no cost introductory access on the basis of developing collaborative grant funding project developments and future licensing fees from successfully commercialized products. QUB has a strong record of developing European and UK collaborative industry grant and knowledge transfer partnership (KTP) projects. In this way QUB management respondents claim that they are " … *flexible and industry-led* … ", including from the selective advice and feedback of advisory board members and the wider CSIT membership, which includes large investor companies such as THALES, BAE and QUB's spin-out part of Nvidia.

Cambridge CSIC developed models to promote innovation. In the first place the programme managers worked with large construction industries such as Mott Macdonald, Skanska, Costain and Arup to permit postdoctoral staff to collaborate on projects so that fiber optic sensors could be piloted in the construction process over a sufficient seasonal adjusting time period. The sensors were used for the ground tests for London's CrossRail tunnelling and building foundations to collect data, analyze and improve operations. The project proved so successful that Skanska establish a dedicated division to use fiber optics for their concrete tunnelling and pile foundations. Estimated industry savings relate to reductions of over one third of material costs through improved monitoring of seasonal ground stress tests. An additional benefit was the development of the successful Utterberry spin-out by a PhD student in 2013. This offers bespoke micro sensors for construction.

12.4. Theme 4: training for management skills – dedicated accelerator courses

The IKCs were financed by the UK Engineering and Physical Sciences Research Council (EPSRC) to incorporate education and training to industry within their ToC programmes. Crucially, this demonstrates that skills training is an important university entfin ecosystem element to support industry innovation take-up, both through entrepreneurial training and coaching for start-ups, but also in delivering specialist skills for existing businesses which facilitate innovation adoption and business development (Owen and Vedanthachari 2022).

QUB developed an internationally leading MSc in cyber security which has produced more than 100 graduates, many of whom have been employed in Belfast's burgeoning cyber security industry cluster. QUB's CSIT management and TTO staff offered evidence of high-quality local job creation in the cyber security sector, with average wages of £46.5k almost double the average annual salary of £28k in a traditionally low-income UK region. CSIT also initially developed an accelerator lab support start-up programme on their Belfast science park site (producing 17 spin-outs), subsequently expanded into the LORCA funded programme with greater UK accessibility through its East London location.

SynbiCITE's mini-MBA course was specifically developed for graduates in synthetic biology to familiarize with start-up opportunities and acquire business-related skills in order to support spin-out start-ups. The partners in this case were high-level university networks in the UK, namely Cambridge, Manchester, Bristol, Nottingham and Edinburgh. These institutions prepared potential collaborators for SynbiCITE's launchpad accelerator support. The mini-MBA programmes are developed to provide training and enable students to use the labs located at Imperial's White City Biofoundry and PoC grants. Business acclimatization and practical business management training is greatly appreciated by SynbiCITE's translation staff. They suggested that management training was essential in addition to technical training in order to work with diverse groups of people and understand their needs.

Cambridge CSIC IKC positioned themselves to provide digital support to the needs of the construction and infrastructure industry. Fiber optic sensors were provided to the construction firms to map, plan and assess the buildings. CSIC's agenda was informed by the need to service the needs of industry. To optimize the use of fiber technology and to acquire greater use and appreciation, over 25 conferences alongside workshops and secondments were arranged. In addition, a uniform tailored approach has been instituted with over 60 industry partners and several trade associations, the British Geological Society and innovative start-ups, to access technical staff support, use of lab equipment and dedicated training workshops for businesses. The networks, and dedicated support were appreciated and endorsed by SMG startup. They acknowledged that CSIC's support to access expensive lab equipment, research data and skills of expert employees to evaluate data and examine findings were valuable. They also mentioned that the Pandemic prevented vital access to labs and caused a more bureaucratic approach. Notably, CSIC's focus on supporting larger construction businesses only resulted in three spin-offs.

12.5. Theme 5: leadership (networking, policy regulation, global outreach)

The IKCs, worldwide and in their industry have gained leadership status. The presence and dominance of IKCs supports the case for developing an ecosystem that enables sectoral focus to develop the institutional linkages to enhance industry standards to build confidence and support development of innovative technology sectors – overcoming information asymmetries to encourage private sector investment to promote small business innovation (Owen and Mason 2019; Munari et al. 2016; Lerner 2010).

The industrial stakeholders acknowledged the role of Cambridges CSIC to promote change at all levels within a conventional industry (construction) to correspond to cutting-edge skills and technologies. CSIC was established in 2011 to encourage cooperation in terms of research between universities and industry. Since the inception, CSIC's events have developed close cooperation with construction industry trade bodies, including the Institute of Civil Engineers (ICE). This cooperation has enabled CSIC to publish two best practice reports by ICE and the Department for Transport. CSIT has international presence and continues to encourage the construction industry to apply the Carbon Reduction Code currently being trialed by the UK Environment Agency. CSIC continues to lead the sector and develop links, for example, with Berkeley University in the US and in South East Asia through e.g., assisting South Korea's national bridge building programme.

Prior to its CSIT IKC establishment in 2009, QUB's Engineering Centre for Information Technology had been driven by the concept of delivering a "*digital tomorrow*" through its Belfast science park location and strategic economic development work in one of the UK's poorest, least entrepreneurial, regions. CSIT seized the opportunity for tech industry specialism and has worked closely with the Northern Ireland and UK governments. Within the UK this saw close working with key stakeholders such as the UK Defense sector, Department for Digital, Media, Culture and Sport and Department for International Trade, including leading participation in trade missions. CSIT has also engaged with large NI employers and encouraged corporate inward investment, with Belfast seen as a source of high-quality cyber security experts to staff local IT back offices. Internationally, CSIT is engaged with the US NSA, participating in the world economic forum and has close linkages to over 30 international research centres, notably in universities in Singapore, Japan, South Korea and Israel.

From our findings (summarized in Table 2), it can be inferred that to deliver industry innovations both public and private funding is required. This suggests, industry and partners may choose different approaches to achieve outcomes. In the case of CSIC, it chose a pull strategy to involve industry professionals into the center, whereas CSIT has adopted push strategy of using translation engineers to push the output generated by research scientist, whilst SynbiCITE chose incubation as the catalyst promoting innovation through funded tech labs.

13. University-led entfin ecosystems – discussion and implications

Three empirical university case studies were studied, namely Cambridge CSIC, Queens CSIT and Imperial SynbiCITE, summarized using five emergent themes: communication, accessibility, project finance, skills and leadership (see Table 2). They demonstrate considerable public funding has been strategically invested into universities with globally leading research to develop their capacity to translate their different new technology platforms into positive commercial innovation impacts. The positive resulting outcomes validate a case for the creation of an entfin ecosystem to promote innovation (North, Baldock, and Ullah 2013; Owen and Mason 2019; Owen 2021; Owen and Vedanthachari 2022). Fostering entfin ecosystems has served to develop collaborations between universities and industry to support the development of cutting-edge technologies (cyber security, synthetic biology) and new innovative applications of technology by industry; notably in relation to the construction sector embracing fiber optic and smart technology. The methodology employed in this study suggests that the entfin ecosystem ought to be evaluated thematically to compare and contrast the emergence and evolution over time. This can promote what works in different sectors and locations to foster research creation and the related industry adoption and commercialization of innovative technologies. Policy which stimulates interactions between universities, government agencies and private sector partnership is shown to promotes innovation capacity in the region, whilst serving as a catalyst for regional, national and global ecosystem and economic development.

These findings reported above, support the view that to facilitate university research translation to industry innovation and commercialization, public funds as well as private co-financing is essential. Notably, it supports the notion of early commercial collaboration to encourage private sector co-financing alongside PoC project grants/subsidies (Owen et al. 2019; Owen 2021). Having assessed the role of universities in overcoming information asymmetries in the early-stage entfin ecosystem, the study offers strong evidence for public policy to create an effective university entfin ecosystem to support creation, and promotion of innovation and their adaption. Here we offer novel contributions to the importance of adopting a holistic university entfin ecosystem approach to public programme, ToC for financing translation and overcoming information asymmetries which constrain private investment and commercialisation of disruptive new technologies (Munari, Sobrero, and Toschi 2018; Owen and Mason 2019; Owen 2021; Owen and Vedanthachari 2022). We further demonstrate clearly the nuances of sector maturity and variation between more investible shorter-term software versus longer horizon capital intensive deeptech, which remains problematic in the UK and global markets (Owen 2021).

First, from a contextual perspective, there is limited funding provided by the IKCs for staff translation and associated network events. However, the evaluation supports the view that funding industry experienced translators is effective in promoting innovation through developing connections to penetrate into industry, thereby achieving real impact (Hauser 2010). In particular, a collaborative investment approach enables all the stakeholders' access to the latest well-equipped labs to take advantage of emerging research. However, latest technologies are expensive, therefore, choices have to be made. In the case of synthetic biology, the approach adopted to develop niche specialism amongst networked universities such as Imperial focusing in AI, and University of Manchester in robotics, has yielded positive results. The collaborative approach assisted cost-sharing and enabled development of regional niche which led to key private industry partnership. This approach was supported by affective policy mix with UKRPIF capital funding complementing IKC revenue funding. This offers an optimal cost-effective policy approach (Munari et al. 2016), with regional economic gains, by sharing knowledge, expertise and finance to create spinouts. This is demonstrated where Manchester University students participate in Imperial's MBA and launchpad programmes and create spinouts in the North of England.

Through innovative PoC and accelerator methodologies, the IKCs attempted to overcome information asymmetries and to generate timely project specific, privately co-fundable commercial solutions (Owen 2021). A core strength of IKCs are their networks with other regional specialist universities, such as Imperial and Southampton's biotech IKCs, and more flexible approach than national early-stage funders (eg Innovate UK grants). IKC specialist tailor-made facilities are effective, efficient, and fast to offer required funds. This process offers a more commercial-minded peer review grant process than typically found in national IUK programmes. Their success in attracting further project funding supports the concept of earlier stage commercial investment linkages leading to greater likelihood of follow-up next stage finance escalator private investment (Owen 2021; Pierrakis and Owen 2022). Flexible approaches are required for different industries and technology applications. Cambridge CSIC funded PoC demonstration projects "in situ" with big construction industry collaborators, whilst SynbiCITE offered technical PoC, access to state of the art testing equipment alongside rounded industry launch-pad support for management skills and next stage investment linkages. This advances Munari et al. (2016) in finding a national programme that has regional university specialist research focus, but also has national and international outreach, which is nuanced by ecosystem factors such as complementary university networks and industry financing mix.

A key observation, derived from the analysis is that commercialization horizons vary over multiple time periods, that gives rise to the information asymmetries challenges, especially for the early-stage innovation investment escalator (Owen, Deakins, and Savic 2019; Harrer and Owen 2022). Software technology, such as cyber security software are normally less capital intensive, tend to have shorter investment horizon, hence attracting more private investment. This assertion is supported by the experiences of Belfast's cyber tech cluster, supported by around 60 businesses that had contributed £80 m GVA. The software sector could rapidly exploit innovation within a short time. In contrast, for longer horizon synbio and biofilm sector companies the overhead costs have fallen in recent years, allowing easier high-level entry and they tend to attract large grants to access big data and attract considerable private investment. However, to develop and operationalize commercial industry innovations, for example to pilot and manufacture synbio products, there is a need for large-scale investment for the "deeptech", high-cost capital equipment. A problem here is that, unlike for example established pharma long horizon investing, private investors (including corporate VCs) do not yet understand the stage funding hurdles of the emerging deeptech synbio sector (Owen and Vedanthachari 2022; Harrer and Owen 2022). Whilst West London's new bio-venture cluster is worth over £1bn, this is largely based on IP and patent potential. Such potential large capital investment projects tend to find it difficult to sustain without UK government grants and co-financing arrangements. This practice is mirrored in the US and Chinese synbio investment markets, but the stark difference between them and the UK is the scale of financial investment. Without government support, the UK's progressive ventures would be lost to overseas competitors. SynbiCITE's managers suggested that government VC co-funding could catalyse considerable private funding into the sector, which currently lacks the private corporate investment funding found in the more mature risk-assessable biopharma sector. An alternative model was also proposed, akin to Harvard's Wyss Institute, which would require backing from a billionaire's foundation.

The analysis above suggests, to realize the UK's full potential, it is imperative to connect the dots by supporting networking, and raising awareness amongst industry and policy leadership of the need to support research and innovation. IKC managers argue that it is essential to closely work with policymakers within government and to undertake political lobbying to influence policy that positively impacts the policy mix (Munari et al. 2016). This is needed to foster, nationally and internationally regulations and good practice amongst the so called “frontier” industries, otherwise referred as “*the wild west*”, that could benefit from better embedded regulatory and technical guidance. The convergence of regulation allows the national and global industry standards to harmonize cross-border practices, reducing uncertainties leading to information asymmetries in early-stage financing in emerging deeptech sectors (Owen and Vedanthachari 2022). To gain competitive advantage, IKCs are essential to support global university research networks. Their importance was observed during the research to develop and deploy COVID-19 vaccines. Equally, they can drive climate change mitigation innovations and developing industry standards, such as the development of sustainable construction practices globally.

14. Conclusions

This paper makes contributions to developing a more integrated understanding of the university entfin ecosystem in financing early-stage new emergent technological innovations in SMEs and industry. In doing so it highlights the interrelated roles of communication, accessibility, skills, leadership and critically finance in supporting the role that universities play in reducing the information asymmetries which inhibit early-stage innovation financing, particularly for new ventures. The paper sheds light on sectoral nuances and the more acute problems of overcoming the information asymmetries which constrain deeptech (Owen 2021). In this respect the paper suggests that an improved, more coherent, policy mix addressing the university entfin ecosystem actors can support early-stage deeptech innovation investment, with potentially strong outcomes for local, national and wider global economies.

15. Limitations and directions for further research

Ecosystems are shaped by local characteristics like skills, culture and government policies and each ecosystem is unique in its own way. This research investigated the activities of three specific and different UK university-led ecosystems and the role and influence of public policy. Further research is required to investigate the relevance of findings to other ecosystems, both within and outside of the UK, in particular to span different policy and financing cultures. Principally, we reveal that deeptech research and technologies have very long lead times from inception to maturity and over their life cycles different actors can play critical, dominant roles. Longitudinal research about the developing maturity of these technologies and the crucial role of finance in shaping these technologies will help to guide policy decisions for other emerging technologies, improving the potential for considerable economic and societal good.

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